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Bifilar Analysis User's Manual—Volume \coprod

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SECTION 1

SUMMARY

This report describes the digital computer program developed to study the vibration response of a coupled rotor/bifilar/airframe system.

The theoretical development of the rotor/airframe system equations of motion is provided in Reference 1 while the fuselage and bifilar absorber equations of motion are discussed in Appendix D.

The modular block approach used in the make-up of this computer program is described in Section 2. Section 3 provides descriptions of the input data needed to run the rotor and bifilar absorber analyses. Sample output formats are presented and discussed in Section 4. The results for four test cases, which use the major logic paths of the computer program, are presented in Section 5. In Section 6, the overall program structure is discussed in detail, including the segmentation procedure (overlay) needed to run the program on the NASA CDC computer system, the routine flow diagrams and a list of the COMMON blocks. Finally, in Section 7, the Fortran subroutines are described in detail.

The work was conducted under NASA contract NAS1-15612, "Bifilar Analysis Study".

SECTION 2

PROGRAM DESCRIPTION

The bifilar absorber analysis was developed to provide the engineer with an analytical tool capable of rapid parametric vibration evaluation of the entire helicopter. A block diagram of the vibration analysis program is shown in Figure 1, where it can be seen that a modular approach has been adopted to form the main program. Modularization is achieved when each component block outputs the mass, damping and stiffness matrices or force vectors with the pertinent degrees-of-freedom (d.o.f.) including the 6 d.o.f. of the attachment point, i.e. 6 d.o.f. at the hub for rotor or bifilar absorber attachment, or 6 d.o.f. in the cabin or cockpit for fixed-system absorber attachment. Where two blocks merge together, the degrees-of-freedom of the attachment point are eliminated and replaced by fuselage modal degrees-of-freedom.

2.1 Analytical Model

Derivation of the coupled analysis is shown in Appendix D.

A description of the analytical model which consists of primarily rotor, fuselage, rotating-system absorbers and fixed-system absorbers is given below.

Rotor

The rotor system is represented by a modal approach which utilizes the equations of motion from Reference 1. The rotor blade degrees-of-freedoms which can be incorporated in the analysis are: up to four blade elastic modes (coupled flatwise/edgewise), up to 2 blade torsional blade modes (first mode represents a rigid blade while the second one is an elastic mode) and rigid blade flapping and lead-lag motions - a total of 8 blade modes which correspond to 24 d.o.f. (each mode has one symmetric and two cyclic components). The rotor/airframe coupling terms are incorporated in the analysis using 5 airframe modes corresponding to uncoupled fuselage longitudinal (x), lateral (y), vertical (z), roll $(\theta_{\rm X})$ and pitch $(\theta_{\rm y})$ motions - yaw motion $(\theta_{\rm 7})$ is not included.

The major assumptions made in the development of the rotor system model are listed below:

- 1. Dynamic and aerodynamic effects assume small perturbations about steady initial values of the system generalized coordinates.
- 2. Aerodynamic forces are developed using strip theory.
- Number of rotor blades must be greater than two due to the polar symmetry assumption made in the rotating system generalized coordinate transformations.

- 4. The following effects are not included in the rotor analysis:
 - a. Forward flight aerodynamics
 - b. Rotor speed d.o.f.
 - c. Variable inflow over the rotor disc
 - d. Unsteady aerodynamics
 - e. Airframe yaw motion

Fuselage

The fuselage dynamic model is a set of linear modal equations which are provided in Appendix D. The computer program accepts inputs of system modal properties of up to 16 airframe modes.

Rotating-System Absorbers

The bifilar analysis includes linear and non-linear inplane rotor-head absorbers and linear vertical absorbers. The forced response analysis can use up to 5 types of linear absorbers (inplane plus vertical). A maximum of 12 non-linear inplane pendulums can be employed in the time history analysis. Viscous damping of the absorbers is assumed.

Fixed-System Absorbers

Fixed system absorbers are modeled in the analysis as a simple unidirectional spring-mass-damper system. The absorbers attachment point must be at a defined modal vector point. Provisions for up to 5 absorbers are provided for in the analysis.

2.2 Program Execution

The rotor/bifilar coupled program starts by calculating the dynamic and aerodynamic rotor/airframe matrices (assuming that rotor coupling has been requested) and couples them with the bifilar analysis fixed system dynamic matrices. Then, it expands the matrices to include the contributions from the fixed system absorbers and the linear inplane and vertical bifilar pendulums. At this point, a decision is made on the type of solution to be calculated: forced response or time-history. If the forced response solution is requested, then the generalized forces are calculated followed by the evaluation of the forced response solution. If the time-history solution is required, then the program proceeds to calculate the dynamic matrices of the non-linear inplane bifilars, adds them to the matrices from the linear analysis, solves for the acceleration vector and integrates it to obtain the velocity and displacement vectors. The final results are harmonically analyzed (up to 10 harmonics can be obtained) and printed out.

Multiple cases, in which any number of input variables are changed, can be easily run (a detailed discussion can be found in Section 5 - TEST CASES RESULTS). If the rotor blade characteristics are not changed, then the rotor matrices are calculated only once, stored and used at a later time as needed.

Computer running time is highly dependent on the total system degrees-of-freedom used and the type of solution requested. The time-history solution requires considerably greater computer time than the forced response solution. Typical computer running times for the time history solution range from one to seven minutes while the forced response execution usually requires from a few seconds to one-half a minute (see Section 5.5 for more details).

When a nonsystem error occurs during the execution of a case, the program attempts to continue using the best data available; if the error is too fundamental for the case to be meaningful, then a partial data printout, followed by an error message, is given before job termination.

SECTION 3

INPUT DESCRIPTION

3.1 Rotor Aeroelastic Analysis Input

3.1.1 Computer Listing of Input for Rotor Aeroelastic Analysis

Symbol	Location	Input Item	Units
RH0	1	Air mass density	Lb sec**2/ft**4
VS	2	Speed of sound	Ft/sec
TL	2 3 4 5 6 7	Tip loss factor	Nd
VIP	4	Rotor axial velocity	Knots
OMEGAI	- 5	Rotor rotational speed	RPM
RIP	6	Rotor radius	Ft
EIP	7	Blade offset	Ft
BLADES	8	No. of blades - must be greater than 2	Nd
KBETA	9	Blade flapping hinge spring constant	Lb-in/rad
KGAMMA	10	Blade lag hinge spring constant	Lb-in/rad
GAMOI	11	Blade prelag angle - lag positive	Deg
BETOI	12	Blade precone angle - up positive	Deg
THETAO	13	Blade collective pitch angle at 75% radiu	
EB	14	Blade Young's modulus	Lb/in**2
YPH2	15	Distance along blade axis from center	
		of rotation to push rod	_
PHL	16	Distance from blade elastic axis to	In
		push rod - positive toward leading edge	
ZETGAM	17	Fraction of critical lag damping	Nd
ZETPIT	18	Fraction of critical blade pitch	Nd
OMOT	10	damping - based on rotor speed	DD14
OMGI	19	Reference rotor speed for defining	RPM
		percent critical lag damping in ground	
VALEMOD	00	resonance studies	A1 1
XNEMOD	20	Number of blade bending modes - up to 4	Nd
75TDL D	21	Open	M.J
ZETBLD	22-25	Fraction of critical damping of blade	Nd
	06 107	bending modes - based on mode frequencies	
ALPHA1	26-105	Open	Mal
WELUNT	106	Blade pitch/lag coupling	Nd

gont de la company de la compa		Control Switches
DUM1(1)	107	Printout of 30 X 30 rotor dynamic (3) and aerodynamic (2) matrices
DUM1(2)	108	0 - no; 1 - yes Printout of KXK (compressed) rotor matrices (dyn. + aero.)
DUM1(3)	109	0 - no; 1 - yes Punch out of KXK (compressed) rotor matrices (dyn. + aero.)
DUM1(4)	110	0 - no; 1 - yes Use of rotor matrices in bifilar anlaysis 0. do not use 1. use new rotor matrices
ROTEST	111	-1. use previous rotor matrices 1. for main rotor 2. for tail rotor
SYSDEF	112 113	Open System definition - ABCDEFGH. A - blade bending B - blade rigid body pitching C - blade rigid body flapping D - blade rigid body lagging E - fixed system modes F - blade elastic pitching G - set to 1 H - set to 1 Element = 0 to include = 1 to exclude
ROTDEF	114	Rotor definition - X. X = 1 blade hinged flatwise and edgewise = 2 blade cantilevered flatwise and edgewise = 3 blade hinged flatwise, cantilevered edgewise = 4 blade cantilevered flatwise, hinged edgewise
ARTIC	115	 = 5 gimbaled rotor Blade pitch input control - XY. X = 1 - pitch bearing follows blade out-of-plane root slope = 0 - pitch bearing remains in plane of hub or preconed position Y = 1 - pitch bearing follows blade inplane root slope = 0 - pitch bearing remains in vertical plane or prelagged position
PRINT	116-11 119	Main printout control - X. X = 3 A, basic calculations + dyn. and aero. integrals = 4 B, A + blade frequency input = 5 C, basic calculations only = 6 D, B + blade frequency output = 7 or greater - same as for X = 3.

5,65	en e	anneteranner ranner renniser rennance					
COLUMN TO THE CONTRACT OF T	DUM2(1)	121-	Propeller moment option in dynamic stiffness matrix O. include propeller moment (default value) 1. exclude propeller moment Open				
Contract Comment of Contract C	124 LAGKII 125		Blade lag damper option O. include lag damper 1. exclude lag damper				
Produce confront			Lag damper physical characteristics				
	L1 L2 L3 L4 L5 L6 CLD KLD	126 127 128 129 130 131 132 133	L1, inches L2, inches L3, inches L4, inches L5, inches L6, inches Damper damping coefficient, lb-sec/in. Damper stiffness coefficient, lb/in.				
	ZETELP CP	134 135 136- 199	Blade elastic pitch modal damping, nd Effective radius to cantilevered point in torsion (defaults to value of blade offset in location 7), in. Open				
	BN	200	Number of elements in blade segment chart - up to 20. These are defined over the length of the blade only - the first segment is at the root of the blade-normally the last segment should be no more than 3 percent radius.				
	RR	201- 249	Segment lengths, inches				

			he following blade properties are input from the center of rotation to the blade tip at specified radial positions				

	NCHI CHORD	250 251- 349	Number of elements in blade chord chart Radius - in : chord - in				
	NATWI ATWIST	350 351- 449	Number of elements in blade aerodynamic twist chart Radius - in : twist - deg (twist down is positive and is zero at 75 percent radius)				

NSTWI	450	Number of elements in blade structural twist chart
STWIST	451-	Radius - in : twist - deg
31W131	549	(twist down is positive. The twist at 75 percent
	919	radius is defined by the blade geometry consistent
		with the definition of aerodynamic twist)
NCGI	550	Number of elements in blade center of gravity chart
CG	551-	Radius - in : CG - in
	649	(CG is positioned relative to and positive ahead of
		elastic axis)
NACI	650	Number of elements in blade aerodynamic center chart
AC	651-	Radius - in : AC - in
	749	(AC is positioned relative to and positive ahead of
NEAT	750	elastic axis)
NEAI EA	750 751-	Number of elements in blade elastic axis chart Radius - in : EA - in
EA	849	(EA is positioned relative to and positive aft of semi-
	043	chord)
		Shot u/
		The following blade properties are defined for a
		specified radial segment
NGJFI	850	Number of elements in flexbeam torsional stiffness
	0.54	(cross-beam rotor design) chart
RGJF	851-	GJ - lb-in**2 : segment length - in
NMBI	949 950	Number of elements in blade weight shart
RMB	950 951-	Number of elements in blade weight chart Weight - lb/in : segment length - in
KND	1049	Mergine - TD/ III . Segment length - III
NIEI	1050	Number of elements in blade edgewise second moment of
		area chart
RIE	1051-	IYY - In**4 : segment length - in
	1149	
NIFI	1150	Number of elements in blade flatwise second moment of
חזר	1151	area chart
RIF	1151-	IXX - In**4 : segment length - in
NFM	1249 1250	Number of elements in blade flatwise mass moment of
141.1.1	1630	inertia chart (about CG)
RFM&FMI	1251-	IF - lb-in-sec**2/in : segment length - in
Section Pin	1349	12 000 =, 1 00g
NEM	1350	Number of elements in blade edgewise mass moment of
		inertia chart (about CG)
REM&EMI	1351-	<pre>IE - lb-in-sec**2/in : segment length - in</pre>
	1449	
NTM	1450	Number of elements in blade torsional mass moment of
ртмотит	1/151	inertia chart (about CG)
RTM&TMI	1451- 1549	<pre>IT - 1b-in-sec**2/in : segment length - in</pre>
NGJI	1550	Number of elements in blade torsional stiffness - GJ
HOOL	1000	chart
RGJ	1551-	GJ - 1b-in**2 : segment length - in
t mentinen sistemaan an	1649	

	and the second contract of the second contrac	Nantantoni e e e e e e e e e e e e e e e e e e e	
Assessed Coloreday			XBR Parameters
The second secon	YA YB FRR	1650 1651 1652 1653- 1669	Distance from center of rotation to outer snubber, in. Distance from center of rotation to inner snubber, in. Distance from center of rotation to flexbeam root, in. Open
		<u>Ta</u>	il Rotor Control System Parameters
	PBM 	1670 1671- 1674	Weight at blade pushrod, lb. Open
	C1	1675 1676- 1679	Damping associated with weight above, 1b-sec/in. Open
	PBK 	1680 1681- 1766	Stiffness associated with weight above, 1b/in. Open
			Main Rotor Control System Parameters
	PBMM C1M PBKM RSB RS	1767 1768 1769 1770- 1772 1773 1774- 1778 1779 1780	Weight at blade pushrod, lb. Open Damping associated with weight above, lb-sec/in. Open Stiffness associated with the weight above, lb/in. Open Distance from center of rotation to pushrod connection on swashplate, in. Distance from center of rotation to servo actuator connections on swashplate, in. Open
			Blade Section Aerodynamic Data
	DRGDAT LIFDAT PMDAT	1850- 2749 2750- 3649 3650- 4548	Drag data Lift data Pitching moment data

03008

3.1.2 Description of Input for Rotor Aeroelastic Analysis

Additional information on the input parameters is provided in this section.

Each input quantity is given in the following format:

Location No., Quantity, Units.

Important details and comments.

1. Air Mass Density, $1b \sec^2/ft^4$.

If set to zero, all aerodynamic calculations are omitted.

2. Speed of Sound, ft/sec.

Used to compute local blade Mach number for lift, drag, and pitching moment calculations.

3. Tip Loss Factor, Nondimensional.

Provides lift and pitching moment loss in the blade tip region. Drag is not affected.

Value should be equal to or greater than one minus the nondimensional length of the blade tip segment. A value of one constitutes no loss.

4. Rotor Axial Velocity, Knots.

Represents climb or sideslip velocity for a main or tail rotor respectively. For propellers this is the forward speed of the aircraft. Positive velocities are in the same direction as the thrust.

5. Rotor Rotational Speed, rpm.

When calculating blade bending frequencies at low rpm's, computer time is greatly increased. It is suggested that rpm not be less than 50 cpm.

6. Rotor Radius, ft.

Measured from center of rotation.

Blade Offset, ft.

Distance from center of rotation to flap and lag hinge. These hinges are assumed to be coincident.

8. Number of Blades, Nondimensional.

Any number greater than 2 since the analysis assumes that the rotors have polar symmetry. The analysis will execute for N=2 but the results are incorrect.

9. Blade Flapping Hinge Spring Constant, 1b in/rad.

If the rotor definition, location 114, stipulates a hinged root boundary condition, the flapping spring provides root flapping restraint in the calculation of the blade elastic modes. It is also used in the rigid-body flapping equation.

10. Blade Lag Hinge Spring Constant, 1b in/rad.

Same comments as above with "lagging" substituted for "flapping".

11. Blade Prelag Angle, Degrees.

Lag positive.

12. Blade Precone Angle, Degrees.

Up positive.

13. Blade Collective Pitch, Degrees.

Aerodynamic blade angle at 75% radius. Leading edge up positive. If affects blade thrust and blade bending frequencies and mode shapes.

14. Blade Young's Modulus, 1b/in².

Used in calculation of blade elastic modes and steady elastic deflections. Appears explicitly in steady elastic deflection calculations and therefore must have a value if the blades are flexible.

15. Distance Along Blade Axis From Center of Rotation to Blade Pushrod, in.

Used in calculation of pitch/flap coupling for rigid-body flapping and for pitch/flap and pitch/lag coupling for elastic blades.

16. Distance From Blade Elastic Axis to Pushrod, in.

Used in calculation of pitch/flap coupling for rigid body flapping, pitch/lag coupling for rigid body lagging, and pitch/flap and pitch/lag coupling for elastic blades. Positive toward leading edge.

17. Fraction of Critical Lag Damping, Nondimensional.

Used only in the rigid-body lag equation. Based on uncoupled lag frequency. This value is ignored if the lag damper option is exercised (loc 125 set to 0).

18. Fraction of Critical Blade Pitch Damping, Nondimensional.

Used only in the blade pitch equation. Based on rotor speed. If, for example, at a given rotor speed the blade torsional frequency is 5 per rev and we wish to incorporate 10% critical damping, we would input 0.5.

19. Reference Rotor Speed, RPM.

Holds the rigid-body lag and pitch damping coefficients, C, constant at the value corresponding to that at the chosen reference rotor speed. If actual rotor speed variations are made, the percentage of critical damping will vary. If this is not desired, a zero should be input.

20. Number of Blade Bending Modes, Nondimensional.

Up to four elastic modes can be used. If rigid-body modes are also being used, the program automatically recognizes this and will provide the correct elastic modes. For example, if two bending modes are requested and rigid-body flapping is being used, the program finds the first three blade modes, eliminates that mode which corresponds to rigid-body flapping, and provides the remaining two modes. A zero locks out elastic modes.

22.-25. Fraction of Critical Damping of Blade Bending Modes, Nondimensional.

Used only in the blade bending equations. Based on modal frequencies.

106. Blade Pitch-Lag Coupling, Nondimensional.

Defined as degrees pitch-up per degress lead for rigid-body lagging motion, or degrees pitch-up per degree blade tip inplane lead angle measured at blade root for elastic modes. Lead/pitch-up positive.

- 107. Printout option for 30 X 30 rotor matrices. The dynamic stiffness, damping and mass matrices and the aerodynamic damping and stiffness matrices are printed out if switch is set to 1.
- 108. Printout option for compressed rotor matrices. Same as above except that only those degrees-of-freedom requested are printed out if switch is set to 1.
- 109. Punchout option for compressed rotor matrices. This option was used before rotor was coupled to bifilar anlaysis internally in the program. It is excercised if set to 1.
- 110. Coupling switch governing use of rotor matrices in the bifilar analysis.
 - 0. = do not use rotor matrices in the bifilar analysis
 - 1. = calculate and use rotor matrices in the bifilar analysis
 - -1. = use previously calculated rotor matrices in the bifilar analysis
- 111. Control Switch for Main or Tail Rotor.
 - 1 = Main Rotor
 - 2 = Tail Rotor
- 113. System Definition.

Exercises primary control in the program. Overrides any contradictory controls. There is one exception: when location 114 equals 5, i.e., a gimbaled rotor. In this case location 114 has executive control whereby digits 1, 3 and 4 of the system definition are ignored. Up to 8 blade degrees-of-freedom (4 bending modes plus 2 torsional modes plus rigid body flapping and inplane motions) can be used in the rotor analysis.

114. Rotor Definition.

When equal to 1, 3, or 4, motion at the hinges is restrained by the springs in locations 9 and 10 as appropriate.

When equal to 5, gimbaled rotor, the program automatically uses rigid-body flapping, and 4 elastic modes with boundary conditions suitably selected to correctly define the first 5 gimbaled rotor modes. See Reference 1 for a complete explanation of this.

Rotor Definition - X.

- X = 1 Blade Hinged Flatwise & Edgewise
 - = 2 Blade Cantilevered Flatwise & Edgewise
 - = 3 Blade Hinged Flatwise, Cantilevered Edgewise
 - = 4 Blade Cantilevered Flatwise, Hinged Edgewise
 - = 5 Gimbaled Rotor

115. Blade Pitch Input Control.

This simply determines whether inboard or outboard blade feathering is being employed. The feathering bearing is always at the root of the blade.

Blade Pitch Input Control - XY.

- X = 1 Pitch Bearing Follows Blade Out of Plane Root Slope
 - = 0 Pitch Bearing Remains In Plane of Hub or Preconed Position
- Y = 1 Pitch Bearing Follows Blade Inplane Root Slope
 - = 0 Pitch Bearing Remains In Vertical Plane or Prelagged Position

119. Main Printout Control.

Provides a graduated printout capability for debugging, etc.

It is generally good practice to use option 5 for the first case of any run in order to establish that all of the input is correct.

Main Printout Control - X.

- X = 3. A, Basic Calculations + Dynamic & Aerodynamic Integrals
 - = 4. B, A + Blade Frequency Input
 - = 5. C, Basic Calculations Only
 - = 6. D, B + Blade Frequency Output
 - > 7. A (Same as X = 3.)

120. Propeller Moment Option - X.

The propeller moment contribution to the blade rigid torsion degree-of-freedom can be accounted for or neglected depending on the rotor blade design. Removal of the propeller moment is necessary when the rotor design employs blade counterweight devices. The propeller moment is given by:

$$M_p = \Omega_1^2 I_p \theta \text{ where}$$

$$I_p = \int_0^2 (I_E - I_F) dx$$

The inertia, I_p , is the difference between the blade edgewise and flatwise mass moments of inertia integrated along the blade span. Rotor speed is Ω and blade torsional deflection is given by $\theta.$ The moment affects only the dynamic stiffness matrix.

X = 0. - Include Propeller Moment
= 1. - Do Not Include Propeller Moment

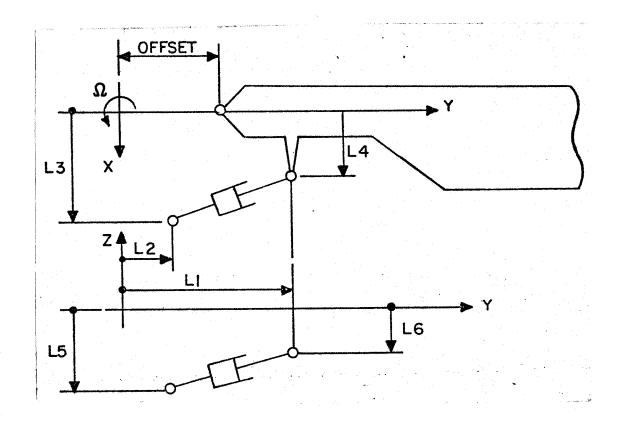
125. Blade Lag Damper Option - X.

X = 0. - Include Lag Damper = 1. - Do Not use Lag Damper

This option allows the use of a blade lag damper which includes all blade motions kinematics and damping and stiffness constants.

A typical arrangement is shown in the sketch below.

The positive convention for the lag damper distances is also shown in the sketch.



Blade Lag Damper Schematic

It should be noted that if a lag damper is used, then input to location 17 is ignored.

126.-134. Refer to the lag damper sketch above.

135. Effective radius to cantilevered point in torsion, in.

All elastic deformation of the blade occurs outboard of this point. For example, in a conventional blade this might be the radius to the pitch horn; in a crossbeam design, it may be the radius to the outboard snubber (if the torque tube is assumed rigid) or it may be the radius to the push rod connection for a torsionally flexible torque tube. The user must use his own judgement in deciding where the cantilever point is situated. If the input cantilever point radius is less than the offset, it is set equal to the offset.

200. Number of Elements in Blade Segment Chart.

Up to 20 may be used. The choice of elements is important, particularly in relation to cross-beam type rotors where it is generally necessary to have smaller elements inboard where the spar is highly twisted. Thus, we may have, for example, 10 elements describing the inboard 25% of the blade, and 10 elements describing the remaining 75%.

201.-220. Segment Lengths, in.

These are defined over the length of the blade only. That is, their sum should equal the blade radius minus the offset. The tip segment should generally be of the order of (1-tip loss factor) times the blade radius.

General Comments for Inputs 250 to 849.

All of these quantities are input as values corresponding to a radial position. The first value is always at the center of rotation and the last at the tip. Linear interpolation is used between adjacent values. Each chart can have up to 49 pairs of radius/value coordinates.

250.-349. Blade Chord, in.

350.-449. Blade Aerodynamic Twist, deg.

Defined positive nose down and must be zero at 75% radius. This distribution is used in the calculation of aerodynamic effects.

450.-549. Blade Structural Twist, deg.

Defined positive nose down and will have a value at 75% radius consistent with the geometric properties of the blade. This distribution is used in the calculation of the blade elastic modes, steady elastic deflections, and blade center of gravity offset effects.

550.-649. Blade Center of Gravity, in.

Positioned relative to, and defined positive ahead of, elastic axis.

650.-749. Blade Aerodynamic Center, in.

Positioned relative to, and defined positive ahead of, elastic axis.

750.-849. Blade Elastic Axis, In.

Positioned relative to, and defined positive aft of, blade semi-chord (for a normal blade, input = - chord/4).

General Comments for Inputs 850 to 1649.

All of these quantities are input as values over a segment length. If an offset exists, the first pair should be "zero, offset". The total of the segment lengths should equal the rotor radius. The weight and stiffness charts can have up to 49 value/segment length pairs. The mass moment of inertia charts can have up to 24 value/segment length pairs.

850.-949. Flexbeam Torsional Stiffness Distribution.

Stiffness: 1b-in², Segment Length: in.

If an effective offset is input, stiffness may be set to zero over this distance.

950.-1049. Blade Weight Distribution.

Weight: 1b/in, Segment Length: in.

1050.-1149. Blade Flatwise Area Moment Distribution.

Area Mom: in⁴, Segment Length: in.

1150.-1249. Blade Edgewise Area Moment Distribution:

Area Mom: in⁴, Segment Length: in.

1250.-1299. Blade Edgewise Mass Moment of Inertia Distribution.

Edg. Mass Mom: 1b in \sec^2 /in, Segment Length: in.

1350.-1399. Blade Flatwise Mass Moment of Inertia Distribution.

Flat. Mass Mom: 1b in sec^2/in , Segment Length: in.

1450.-1499. Blade Torsional Mass Moment of Inertia Distribution.

Tors. Mass Mom: 1b in sec^2/in , Segment Length: in.

1550.-1649. Blade Torsional Stiffness Distribution.

Stiffness: 1b-in², Segment Length: in.

Zeros may be input up to the cantilever point radius (loc. 135). Do not include flexbeam stiffness in

this chart.

1650. Distance From Center of Rotation to Outer Snubber, in.

1651. Distance From Center of Rotation to Inner Snubber, in.

Locations 1650 and 1651 have a value other than zero only when cross-beam type rotors are being treated. Nonzero values instruct the program to apply the collective pitch at the outer snubber location. The spar, or structural, blade angle inboard of the outer snubber location is then made equal to the sum of the collective pitch (which is reduced linearly from the value at the outer snubber to zero at the blade root) and the input structural twist. The aerodynamic blade angle inboard of the outer snubber is made equal to the value at the outer snubber.

The torque tube is assumed to be rigid in calculations

of pitch/flap coupling.

1652.	Distance	From	Center	of	Rotation	to	Flexbeam	Root,	in.
				•					

This is the radius at which torsional deformations of the flexbeam may be assumed to be zero. This radius is also used in defining the twist distribution for blade bending mode computations.

Tail Rotor Control System Parameters

1670. Weight at Blade Pushrod, 1b.

1675. Damping Associated With Weight Above, 1b-sec/in.

Series Stiffness of One Arm of Pitch Beam, Pushrod, and Pitch Horn for Pitch Beam Assumed Cantilevered at its Center, 1b/in.

Main Rotor Control System Parameters

1767. Weight at Blade Pushrod, 1b.

1769. Damping Associated With Weight Above, 1b-sec/in.

1773. Stiffness Associated With Pushrod, Swashplate Connection, Pitch Horn, etc..., lb/in.

1779. Distance From Center of Rotation to Pushrod Connection on Swash Plate, in.

1780. Distance From Center of Rotation to Servo Actuator Connection on Swash Plate, in.

Blade Section Aerodynamic Data

Drag, lift, and pitching moment data are each input in sets of CD, CL, or CM pairs corresponding to up to 12 Mach numbers.

Any or all of the data charts can be omitted.

In each chart there are up to 35 pairs of angle-of-attack and CD, CL, or CM data corresponding to each Mach number.

A total of 75 locations are allocated to each Mach number.

Mach numbers and angles-of-attack are input in ascending order.

If charts are employed use no less than 2 Mach numbers and 5 pairs of data per chart.

The input angle-of-attack range should exceed the expected range for the condition being analyzed.

Unsymmetric airfoil data can be used.

Only one set of airfoil data can be used.

Example of input format:

3650.-4549.

1850 1851 1852-1924 1925 1926 1927-1999 Etc.	Number of pairs for first Mach number First Mach number Angle-of-attack: CD pairs Number of pairs for second Mach number Second Mach number Angle-of-attack: CD pairs
18502749.	Drag Data.
27503649.	Lift Data.

Pitching Moment Data.

3.2 Bifilar Analysis Input

3.2.1 Computer Listing of Input for Bifilar Analysis

COMPUTER LISTING OF INPUT TO THE BIFILAR ANALYSIS

SYMBOL	LOCATION	DESCRIPTION	UNITS
NINBF NAP	1 2	KINDS OF INPLANE BIFILARS =< 5 NUMBER OF AIRCRAFT STATION POINTS	
WF NIMP	3 4	TO EVALUATE RESPONSE =< 4 FORCING FREQUENCY DIMENSION OF IMPEDANCE MATRIX	CYCLES/REV
XNARM OMEGAR NFABS NF IWRITE	5 6 7 8 9	NUMBER OF FIXED SYSTEM ARSOPREDS =< 5	RPM
NVBIF XNARM RHM ICHECK	12 13 14 15	KINDS OF VERTICAL BIFILARS =< 5 TOTAL NUMBER OF VERTICAL BIFILARS=< 10 =1. CALCULATE ROTOR HEAD MOTION ONLY =1. WRITE M,C,K MATRICES AND IMPEDANCE OPEN	
	17 18 19	=0. NO PRINTOUT OF ROTOR MATRICES =1. GET PRINTOUT OF ROTOR MATRICES =0. NO NON-LINEAR INPLANE BIFILARS =1. USE NON-LINEAR INPLANE BIFILARS OPEN	
		FIXED SYSTEM ABSORBER DATA	
FABSM FABSWN FABSD	20-29 30-39 40-49	FIXED SYSTEM ABSORBER MASS ARRAY FIXED SYSTEM ABSORBER FREQUENCY ARRAY FIXED SYSTEM ABSORBER DAMPING ARRAY	BUGS CPM
		FIXED SYSTEM MODAL DATA	
XMG XWN XDP	50-69 70-89 90-109	GENERALIZED MODAL MASS ARRAY GENERALIZED MODAL FREQUENCY ARRAY GENERALIZED MODAL DAMPING ARRAY	BUGS CPM
		FORCES AND MOMENTS DATA	
FHC FHS FTC	120-129	COSINE COMPONENT OF HUB FORCES & MOMENTS SINE COMPONENT OF HUB FORCES & MOMENTS COSINE COMPONENT OF TAIL ROTOR LOADS	LB & IN-LB

```
SINE COMPONENT OF TAIL ROTOR LOADS
COSINE COMPONENT OF HORIZONTAL TAIL LOADS
SINE COMPONENT OF HORIZONTAL TAIL LOADS
COSINE COMPONENT OF LOADS OF ANOTHER POINT
FTS
           140-149
FFC
           150-159
                                                                                 77
           160-169
FFS
FEC
           170-179
                                                                                 **
                                COMPONENT OF LOADS OF ANOTHER POINT
FES
           180-189
                       SINE
                       INPLANE BIFILAR PENDULUMS DATA
BIFM
           190-199
                       INPLANE BIFILAR MASS ARRAY
                                                                             BUGS
                       BIFILAR ARM FROM CENTER OF ROTATION
           200-209
BARM
                                                                             IN
BIFWN
           210-219
                       INPLANE BIFILAR TUNING FREQUENCY ARRAY
                                                                             CYCLES/REV
           220-229
                       INPLANE BIFILAR DAMPING ARRAY
                       VERTICAL BIFILAR PENDULUMS DATA
BIFM
           230-239
                       VERTICAL BIFILAR MASS ARRAY
                                                                             BUGS
                                                                           BU0
In
                      BIFILAR ARM FROM CENTER OF ROTATION
VERTICAL BIFILAR TUNING FREQUENCY ARRAY
VERTICAL BIFILAR DAMPING ARRAY
BIFARM
           240-249
                                                                          CYCLES/REV
BIFWN
           250-259
           260-269
BIFDAM
           270-449
                       OPEN
                       TRANSFER MATRIX TO MODAL COORDINATES FOR MAIN ROTOR IMPEDANCE (6 X NF)
           450-549
XPHI
       MODE SHAPES OF 2 AIRCRAFT STATIONS WHERE LOADS ARE APPLIED
XPF
                     FIRST AIRCRAFT STATION (6 X NF)
SECOND AIRCRAFT STATION (6 X NF)
           550-649
XPE
           650-749
             MODE SHAPES OF FIXED SYSTEM ABSORBERS & TAIL ROTOR HUB
XPHABS
           750-849
                      FIXED SYSTEM ABSORBER COUPLING MATRIX (NFABS X NF)
                       (20 SPACES RESERVED FOR EACH ABSORBER)
                       TAIL ROTOR HUB TRANSFER MATRIX
           850-949
           950-999
                      OPEN
                   MODE SHAPES OF AIRCRAFT STATION POINTS
XPHAP 1000-1399
                      COUPLING MATRIX OF AIRCRAFT STATION POINTS
                                    (6 X NF X NAP)
                      1000-1099 FOR FIRST AIRCRAFT STATION
1100-1199 FOR SECOND AIRCRAFT STATION
1200-1299 FOR THIRD AIRCRAFT STATION
                       1300-1399 FOR FOURTH AIRCRAFT STATION
----- 1400-1489 OPEN
                          PRINTOUT OPTIONS
                      =0. PRINTOUT IS NOT WANTED =1. PRINTOUT IS WANTED
                *************
                       A =
FSPNT
          1490
                                 FIXED SYSTEM MATRICES
                        = A + ROTOR MATRICES
FSRPNT
          1491
                       В
                        = B + FIXED SYSTEM ABSORBERS
= C + INPLANE BIFILAR PENDULUMS
FSAPNT
          1492
IBPPNT
          1493
                         = D + VERTICAL BIFILAR PENDULUMS
VBPPNT
          1494
                      INPLANE BIFILAR MATRICES ONLY (9 X 9)
VERTICAL BIFILAR MATRICES ONLY (9 X 9)
          1495
IBQPNT
VBQPNT
          1496
IGAMMA
          1497
                      PRINTOUT OF "GAMMAS" (DEGREES-OF-FREEDOM)
          1498
ICUSE
                       =0. DO NOT USE INITIAL CONDITIONS OPTION
```

148.899.0

	1499		NITIAL CONDITIO TIONS 1720-1939	NS FROM PREVIOUS)	CASE
*****	**** END	OF INPUT F	OR LINEAR BIFIL	AR ANALYSIS ***	********
*****	** INPUT	FOR NON-LIN	EAR INPLANE BI	FILARS ANALYSIS	*****
	INPLA	NE BIFILAR	PENDULUMS CHARA	CTERISTICS	
BM DP	1500-1519	BIFILAR W	EIGHTS		LBS
WP BR	1540-1559	BIFILAR N	ATURAL FREQUENC	IES R OF ROTATION NS	CYCLES/REV
PSIR	1580-1599	RELATIVE	AZIMUTH LOCATIO	NS	DEGREES
	H 	UB FORCES &	MOMENTS HARMON	ICS INPUT	
			COS(K*PSI) + S ROUGH A MAXIMUM		
FVV	1/00-1/10	LONOTTURE	NAL DUD FORCE	************** (X) (Y)	LBC
FYY FZZ	1620-1639 1640-1659	LATERAL VERTICAL	HUB FORCE HUB FORCE	(X) (Z) (THETAX) (THETAY) (THETAZ)	LBS LBS
XXM YYM	1660-1679	ROLL	HUB MOMENT	(THETAX)	IN-LB IN-LB
ZZM	1700-1719	YAW	HUB MOMENT	(THETAZ)	IN-LB
GAMMAD	1720-1739 1740-1759	INITIAL B	IFILAR ANGULAR	DISPLACEMENT	RADIANS RAD/SEC
PSIP DPSI	1760	FORCE RAM	P FACTOR(3. IS	VELOCITY RECOMMENDED)	
FPSI NBIF	1762	MAXIMUM A	ZIMUTH ANGLE	=12) ARMONICS (MAX=10) ABLES HARMONICS(MIT AN INPUT ITEM)	DEGREES
NHFH XNH	1764	NO. OF IN	PUT HUB FORCE H	ARMONICS (MAX=10) ABLES HARMONICS(M	16V-10)
PSI	1766	INTEGRATI	ON VARIABLE (NO	T AN INPUT ITEM)	HV-10)
NFP	1/6/	IS APPLIE	D BESIDES ROTOR	HEAD (=< 2)	
			VARIABLES INITI	N LOC. 550-749)	
מפווט					پيد نيد منڌ سب سد چه سه سه سا سه سه سه سه
HUBV	1774-1779	HUB INITI	AL DISPLACEMENT AL VELOCITIES	DICEL ACEMENTS	
TVL	1860-1939	STATE VAR	IABLES INITIAL IABLES INITIAL	VELOCITIES	
FORCES & MOMENTS HARMONICS INPUT OF 2 ADDITIONAL AIRCRAFT POINTS					
			COS(K*PSI) + S		
	(MODE SHAPES	ARE INPUT IN L	OC. 550-749)	
P1FX P1FY	1940-1959 1960-1979	POINT 1	LONGITUDNAL LATERAL	(X) (Y)	LBS LBS
P1FZ	1980-1999	. 17	VERTICAL	(Z)	LBS
P1MX P1MY	2000-2019 2020-2039		ROLL PITCH	(THETAX) (THETAY)	IN-LB IN-LB

P1MZ P2FX P2FY P2FZ P2MX P2MY P2MZ	2040-2059 2060-2079 2080-2099 2100-2119 2120-2139 2140-2159 2160-2179 2180-2199	POINT 2	YAW LONGITUDINAL LATERAL VERTICAL ROLL PITCH YAW	(THETAZ) (X) (Y) (Z) (THETAX) (THETAY) (THETAZ)	IN-LB LBS LBS LBS IN-LB IN-LB IN-LB
	succ	ESSIVE CA	SES CONTROL SWI	тсн	يت سند سند رسيد رشيد رشيد سند سند جمه چنيد سيد سيد سند رساد م
CODE	2200		LETES LAST CASE BACK TO ROTOR		EXT CASE
****	·********	END OF 1	NPUT LOCATIONS	*********	******

3.2.2 Description of Input for Bifilar Analysis

Additional information on the input parameters is provided in this section.

Each input quantity is given in the following format:

Location No., Quantity, Units Important Details and Comments

Linear Analysis Input (Loc 1-1498)

1. Kinds of Inplane Bifilars, Nondimensional.

Up to 5 kinds of inplane bifilars can be used in the analysis if no vertical bifilars are present. The combined number of kinds of inplane and vertical bifilars cannot be greater than 5. This corresponds to a maximum number of 15 degrees-of-freedom (including collective and 2 cyclic motions). Ex. loc 1=2 if one set of 3P and one set of 5P inplane bifilars are employed.

Aircraft Station Points, Nondim.

Due to computer storage requirements, a maximum of 4 points can be used.

Forcing Frequency, Cycles/Rev.

Frequency at which the bifilars will respond divided by the rotor speed.

4. Impedance Matrix Dimension, Nondim.

This location is 2 times the number of fixed system modes loaded in location 9.

6. Number of Inplane Bifilars, Nondim.

The actual number of inplane bifilars present in each kind as defined in loc. 1. It should be noted that, if more than one kind of inplane bifilars is used, then the number of bifilars in each kind has to be the same. The maximum number allowed is 10.

7. Rotor Speed, RPM.

Used to non-dimensionalize frequency units.

Number of Fixed System Absorbers, Nondim.
 The total number of fixed system absorbers is limited to 5.

9. Number of Fixed System Modes, Nondim.

The maximum number of fixed system modes is 16 which allows for 6 rigid body modes (if desired) and 10 flexible modes.

Rigid airframe modes should not be used in the non-linear bifilar analysis.

Program will not execute if number of modes is zero.

10. Extensive Printout Option, Nondim.

Set this location to 1. to obtain additional printout for debugging use.

12. Kinds of Vertical Bifilars, Nondim.

Up to 5 kinds of vertical bifilars can be used if no inplane bifilars are present. Otherwise, the total of the two kinds is 5.

13. Number of Vertical Bifilars, Nondim.

Actual number of vertical bifilars present in each kind as defined in loc. 12. Same number of bifilars is assumed for each kind. Maximum number is 10.

14. Rotor Head Motion Switch, Nondim.

If this control is set to 1. then only the rotor head motion will be calculated.

15. Additional Printout Option, Nondim.

If set to 1., stiffness, damping and mass matrices are printed out for debugging purposes.

17. Rotor Matrices Printout Option, Nondim.

If set to 1., the input matrices to the bifilar anlaysis from the rotor aeroelastic program are printed out. Order is stiffness, damping and mass. The stiffness and damping matrices include aerodynamics if air density is non-zero.

18. Linear/Non-Linear Analysis Option, Nondim.

If set to zero, then linearized inplane bifilar equations

of motion are used and the forced response of all components is calculated. Sample runs using 16 and 28 degrees-of-freedom required 3 seconds and 25 seconds respectively.

If set to 1., then the full non-linear inplane bifilar equations of motion are used and a time history solution is calculated. Computer time for the non-linear option is highly dependent on the number of degrees-of-freedom used. A sample run with 17 d.o.f. took 1 minute and 8 seconds requiring 13 rotor revolutions for convergence of the bifilar motions. A sample run with 29 d.o.f. took 7 minutes and 7 seconds of computer time and required 16 rotor revolutions for convergence.

- 20.-29. Fixed System Absorber Masses, Lb-sec²/in. or Bugs

 Absorber weight in pounds divided by 386.4. Although 10 locations are provided, only 5 can be used (see loc. 8).
- 30.-39. Fixed System Absorber Frequencies, Cpm
- 40.-49. Fixed System Absorber Damping, Nondim.

 Damping associated with the absorber i.e., .01 corresponding to 1% critical.
- 50.-69. Fixed System Generalized Masses, Lb-sec²/in or Bugs

 Maximum number of masses is actually 16 (see loc. 9)
 although 20 computer locations have been allowed.
- 70.-89. Fixed System Generalized Frequencies, Cpm
- 90.-109. Fixed System Generalized Damping, Nondim.

Forces and Moments Data - General Comments, Lb & In-1b

110.-189. The Forces and Moments are Defined in the Fixed System.

The order of the forces and moments input data is: x, y, z, θ_x , θ_y , θ_z , which correspond to longitudinal, lateral, vertical, roll, pitch and yaw motions respectively. The coordinate system used is a right-handed (system with the x-axis defined as positive aft and y-axis as positive out of the right wing).

Thus only six locations are needed to define an input force or moment although 10 computer locations have been allocated.

Examples of input of hub forces (loc. 110-129):

- a) For a 4P inplane bifilar, to load a pure 5P hub force, then F_{χ} (cosine) = $-F_{\gamma}$ (sine) (loc. 110 = loc. 121) and F_{γ} (cosine) = F_{χ} (sine) (loc. 111 = loc. 120).
- b) To load a pure 3P hub force, then F_{χ} (cosine) = F_{y} (sine) (loc. 110 = loc. 121) and F_{y} (cosine) = $-F_{\chi}$ (sine) (loc. 111 = loc. 120).

Additional forces/moments inputs can be specified for the tail rotor (loc. 130-149), the horizontal tail (150-169) and one other arbitrary point (loc. 170-189).

190.-199. Inplane Bifilar Masses, Lb-sec²/in. or Bugs

Bifilar weights divided by 386.4 are loaded for each kind of bifilar used (see loc. 1). The limit on the number of bifilar kinds which can be used is 5 although 10 computer locations are available.

- 200.-209. Inplane Bifilar Arm From Center of Rotation, In.
- 210.-219. Inplane Bifilar Tuning Frequency, Cycles/Rev

The linear inplane bifilar tuning frequency is defined by

F² = R/r where R = bifilar arm (loc. 200-209) r = bifilar distance from hinge to bifilar center of mass

Example: Given R = 18.22 in, r = 2.02444, then F = 3.0 per rev

- 220.-229. Inplane Bifilar Damping, Nondim.
- 230.-239. Vertical Bifilar Masses, Lb-sec²/in. or Bugs

 Same comment as for inplane bifilar (see loc. 12).
- 240.-249. Vertical Bifilar Arm From Center of Rotation, In.
- 250.-259. Vertical Bifilar Tuning Frequency, Cycles/Rev

The linear vertical bifilar tuning frequency is defined by $F^2 = (R+r)/r$ where R = bifilar arm (loc. 240-249) r = bifilar distance from hinge to bifilar center of mass

Example: Given R = 18.50 in, r = 1.23333 in, then F = 4.0 per rev

- 260.-269. Vertical Bifilar Damping, Nondim.
- 450.-549. Transfer Matrix to Modal Coordinates for Main Rotor Impedance, In/in & Rad/in.

The main rotor hub transfer matrix has the dimensions 6 X NF (where NF is the number of fixed system modes defined in loc. 9). Since the maximum value of NF is 16, then 96 computer locations are necessary to define the largest transfer matrix.

The first mode is loaded into locations 450-455, the second mode into locations 456-461, etc. .. until the last or 16th mode into locations 540-545.

For each mode, the order of input is x, y, z, θ_X , θ_Y , θ_Z . The units of the linear motions are in/in while rotations are in rad/in. The user must be careful to load the mode shapes corresponding to the fixed system modes masses, frequencies and damping values from locations 50-109.

- 550.-649. Mode Shapes for First Aircraft Station Where Loads Are Applied, In/in. & Rad/in
- 650.-749. Mode Shapes for Second Aircraft Station Where Loads Are Applied, In/in & Rad/in

Same comments as for the main rotor hub transfer matrix above apply for these inputs.

750.-849. Fixed System Absorber Coupling Matrix, In/in & Rad/in

The fixed absorber coupling matrix has the dimension NFABS X NF (where NFABS is the number of fixed system absorbers from location 8). The modal response in one direction (vertical, lateral or longitudinal) for each fixed system mode (as defined in location 9) is loaded in locations 750-769 for the first absorber, in locations 770-789 for the second, and so on.

850.-949. Tail Rotor Hub Transfer Matrix, In/in & Rad/in

Same comments as above for main rotor hub transfer matrix (loc. 450-549).

1000.-1399. Mode Shapes of Aircraft Station Points, In/in & Rad/in

The response of 4 aircraft stations can be analyzed according to the mode shapes input in locations 1000-1099 for the first station, 1100-1199 for the second, 1200-1299 for the third, and 1300-1399 for the fourth station.

The mode shapes are loaded in the same manner as described above for the main rotor hub (loc. 450-549).

1490.-1494. Printout Options, Nondim.

If any printout option switch is set to 0., then the printout of the corresponding matrices is suppressed. If printout of the matrices is desired, then the proper switch should be loaded as 1.

The build-up of the matrices is as follows:

(loc. 1490) 1. Fixed system matrices (16 X 16 max)

(loc. 1491) 2. Add rotor matrices (24 X 24 max → 40 X 40 max total)

(loc. 1492) 3. Add fixed system absorbers (5 X 16 $max \rightarrow 45$ X 45 max. total)

(loc. 1493) 4. Add linear inplane bifilars

(loc. 1494) 5. Add vertical bifilars (combined with inplane bifilars, the matrices are 15 X 15 max → 60 X 60 max. total)

Thus, the maximum number of degrees-of-freedom which can be handled at the present time with the linear rotor/bifilar coupled program is 60.

Location 1493 also controls the printout of the "Final Combined Mass Matrix" for the non-linear analysis option.

1495.-1496. Bifilar Pendulums Printout Switches, Nondim.

The individual contributions to the coupled system matrices from the inplane and vertical bifilars can be obtained through the use of the printout options as defined in locations 1495 and 1496 respectively.

The results of the forced response analysis for all the system degrees-of-freedom can be printed out through this switch.

1498. Initial Conditions Option, Nondim.

This option applies only when the non-linear analysis is requested (loc. 18 = 1.). If set to 1.0, then the initial conditions to be used should be loaded in locations 1720-1939. Input to these locations is printed out at the end of a non-linear analysis run.

Non-Linear Analysis Input (Loc. 1500-2179)

1500.-1519. Inplane Bifilar Pendulum Weights, Lbs.

The weight of each bifilar pendulum in pounds is loaded according to the number of pendulums from loc. 1763. The maximum number of pendulums allowed is 12.

- 1520.-1539. Inplane Bifilar Pendulum Damping, Nondim.
- 1540.-1559. Inplane Bifilar Pendulum Frequencies, Cycles/Rev

 Same comments as provided for the linear inplane bifilars (loc. 210-219) apply here.
- 1560.-1579. Inplane Bifilar Pendulum Arms From Center of Rotation, In.
- 1580.-1599. Relative Azimuth Locations of Inplane Bifilar Pendulums, Deg

Example: If four inplane pendulums are analyzed, then locations 1580-1583 are respectively 0., 90., 180., 270.

1600.-1719. Hub Forces and Moments Input, Lbs and in.-lb

For the non-linear analysis, the fixed system hub forces and moments are input in harmonics format. Up to 10 harmonics can be used. Cosine and sine components of each harmonic are input alternately.

Ex. Loc 1600 - Longitudinal motion - cosine component of first harmonic

Loc 1601 - Longitudinal motion - sine component of first harmonic

Loc 1602 - Longitudinal motion - cosine component of second harmonic

Etc...

Location 1764 is used in conjunction with the input loads.

1720.-1739. Initial Bifilar Angular Displacements, Radians

These locations are used if the initial conditions switch (loc. 1498) is 1. These values are printed out at the end of a converged time history solution for each inplane bifilar.

1740.-1759. Initial Bifilar Angular Velocity, Rad/Sec

Same comments as above for the initial displacements.

1760. Force Ramp Factor, Nondim.

The hub loads are imposed on the rotor/bifilar/fixed system coupled system as a ramp input dependent on the maximum azimuth angle (loc. 1762) for the time history solution and the ramp factor.

Example: If loc. 1762 = 4320 degrees (or 12 revolutions) and loc. 1760 = 3.0, then the hub loads (loc 1600-1719) are applied linearly in the azimuth interval from zero to 4320/3 (which equals 1440 degrees or 4 revolutions).

1761. Azimuthal Increment For Time History Solution, Degrees

A value of 2 degrees is recommended. However, if the time history does not converge, lower values can be tried to eliminate what may possibly be a numerical instability. It should be noted that the computer execution time is directly proportional to the size of this input quantity.

1762. Maximum Azimuth Angle, Degrees

It is recommended that values corresponding to 10 to 20 rotor revolutions (3600 and 7200 degrees respectively) be used in this location. As for loc. 1761 above, the computer execution time is also dependent on this input. If the time history does not meet the convergence criteria, then it will terminate when the integration azimuthal angle equals the input value in loc. 1762.

1763. Number of Inplane Bifilar Pendulums, Nondim.

A maximum number of 12 bifilars can be used.

1764. Number of Input Hub Force Harmonics, Nondim.

A maximum number of 10 harmonics, corresponding to the input loads in loc. 1600-1719, can be used.

1765. Number of Output State Variables Harmonics, Nondim.

This location governs the number of harmonics analyzed and printed out for the following variables:

1. Bifilar pendulum response, degrees

2. Hub response $(x, y, z, \theta_X, \theta_Y, \theta_Z)$, g's 3. Aircraft stations response (x, y, z), g's

The state of the s

Up to 10 harmonics may be requested.

1767. Number of Aircraft Additional Points Where Loads Are Applied, Nondim.

This number is equal or less than 2. If non-zero, then load appropriate mode shapes in locations 550-749.

1768.-1773. Hub Initial Displacements, In or Rad

At the completion of the time history solution, the hub displacements are printed out to be used for successive cases if desired. The output yields, in order, the longitudinal, lateral, vertical, roll, pitch and yaw motions.

1774-1779. Hub Initial Velocities, In/sec or Rad/sec

Same comments as above for the hub initial displacements.

1780.-1859. State Variables Initial Displacements, In or Rad

The initial displacements of all the degrees-offreedom (except the non-linear inplane bifilar pendulums) are printed out for use in successive cases. The order of printout is:

1. Fixed system

2. Rotor (if required) 3Fixed system absorbers

4. Linear inplane bifilars

5. Linear vertical bifilars

1860.-1939. State Variables Initial Velocities, In/sec or rad/sec.

Same comments as made above for the initial displacements.

1940.-2179. Aircraft Additional Points Forces and Moments Input, Lbs and in-lb.

Refer to comments on hub forces (locations 1600-1719).

2200. Successive Cases Control Switch, Nondim.

If successive runs are to be made, then location 2200 is set to zero. The program then goes back to the rotor aeroelastic analysis and starts execution of the next case. The last bifilar analysis case must have a 1. in location 2200 for proper termination of the computer run.

The maximum number of degrees-of-freedom which can handled by the linear and non-linear analyses are respectively 60 and 72. A breakdown of the individual component maximum d.o.f. is presented in the chart below.

Component		Maximum N	lo. of D.O.F.	Input	
Des	cription	Linear	Non-Linear	Location(s)	
1.	Linear Bifilars (inplane + vertical)	15	15	1 & 12	
2.	Fixed System Absorbers	5	5	8	
2. 3.	Fixed System Modes	16	16	9	
4.	Rotor Blade	24	24	, =	
5.	Non-linear Inplane Bifilars	-	12	1763	
	Total →	60	72		

3.3 Input Data Format

All data is input via cards or card-like images with the following (loader) format. Column 2 represents the number of data values on the card, columns 3-6 give the location numbers of the first data values, successive data values are loaded into successive locations, and columns 7-66 contain the data values in fields of 12, the default format being 5E12.4. A minus sign in column 1 indicates the end of a case. Subsequent cases are loaded immediately after this card in the same format. See subroutine LOADIT for a more detailed description of data cards.

SECTION 4

OUTPUT DESCRIPTIONS

4.1 Rotor Aeroelastic Analysis Output

If the rotor coupling option is exercised (location 110 is not zero), then a listing of the input rotor data is first printed out. A sample page of this output can be seen in Figure 2. The input cards are listed out as read by the computer. For successive cases, only the new input items will be printed out to reflect the changes made between runs. This information is provided for all printout options.

The output formats which follow are obtained for all printout options, as provided in location 119. Additional printout of blade bending frequency calculations and dynamic and aerodynamic integrals evaluations can be obtained if the printout switch is not equal to 5. These formats are not shown here for sake of brevity - they are mainly used for debugging purposes.

Input and calculated dynamic and aerodynamic characteristics of the rotor blade and fixed system are presented in Figures 3a through 3h. Additional explanations are provided in Table 1 below. Some differences may appear in the output formats from the input data due to corrections applied by the computer program to eliminate possible inconsistencies in the input control options.

The abbreviations used in the output formats are listed and discussed in the table below. It should be noted that some input quantities have been preset within the computer program since some program capabilities were not needed for the coupling of the rotor and bifilar systems.

TABLE 1. Rotor Analysis Output Description

Output Symbol	Quantity Description	Input Location	Present <u>Value</u>	Figure Number
PHIXPH PHIZPH	Blade Bending Mode Coupling Factors Blade Bending Mode Coupling Factors	- -	- -	3a
	Lag Damper Quantities			
PHELD	Edgewise Bending Mode at Lag Damper			
PHEPLD	Edgewise Bending Mode Slope at Lag Damper	-		
PHFLD	Flatwise Bending Mode at Lag Damper	.—	-	
PHFPLD	Flatwise Bending Mode Slope at Lag			
QEOLD	Damper Edgewise Steady Deflection at Lag Damper		-	

Output Symbol		Input cation	Present <u>Value</u>	Figure <u>Number</u>
QEOPLD QFOLD	Edgewise Steady Slope at Lag Damper Flatwise Steady Deflection at Lag Damper	-	_	3a
QFOPLD PHLD	Flatwise Steady Slope at Lag Damper Torsional Mode Shape at Lag Damper	. -	<u>-</u>	
THTLD	Blade Twist at Lag Damper		, 	
PHOS	Torsional Mode Shape at Outboard Snubber	-	-	
XNAMOD VF	Number of Fixed System Modes Forward Flight Speed	-	5. 0.	3b
	Control Switches			
ROTEST FTEST	Rotor Definition Flight Definition	111	- 1.	
SYSDEF	System Definition	113	1	
ROTDEF ARTIC	Rotor Definition Blade Pitch Input Control	114 115	-	
PHASE	Phasing Matrix Printout Control	-	0.	
VECT TRMASC	Eigenvector Printout Control Tail Rotor Main Mass Control	-	0. 1.	
SUMASC	Tail Rotor Subsidiary Mass Control	-	111.	
TSERVC MRMASC	Tail Rotor Servo Control Main Rotor Mass Control	<u> </u>	1. 1.	
MSERVC	Main Rotor Servo Control	_	111.	
CIR	Circulatory Unsteady Aerodynamics Control	-	1.	
CIRN	Noncirculatory Unsteady Aerodynamics Control		1.	
LAGKII	Lag Damper Control	125	-	
ZETBLD	Fraction of Critical Damping of Blade Bending Modes	22-25	. -	
	<u>Fixed System Modes</u>			
ZETG	Fraction of Critical Damping of Fixed System Modes	-	0.	
MG	Generalized Mass of Fixed System Modes	-	0.	
OMF PHY	Frequency of Fixed System Modes Lateral Fixed System Mode Shape		0. 0. & 1.	
	(Second Mode Only Equals 1.0)	-		
РНХ	Longitudinal Fixed System Mode Shape (First Mode Only Equals 1.0)	· 	0. & 1.	
PHZ	Vertical Fixed System Mode Shape (Third Mode Only Equals 1.0)	-	0. & 1.	

Output Symbol	Quantity Description	Input Location	Present <u>Value</u>	Figure <u>Number</u>
PHTY	Pitch Fixed System Mode Shape	· <u>+</u>	0. & 1.	3b
PHTX	(Fifth Mode Only Equals 1.0) Roll Fixed System Mode Shape	-	0. & 1.	reconstitution
	(Fourth Mode Only Equals 1.0)		0. 0. 1.	
R	Radius of the Blade Element Mid- Points From Center of Rotation	201-220	-	3c
AC	Blade Aerodynamic Center	650-749	-	e e e e e e e e e e e e e e e e e e e
CG	Blade Center of Gravity	550-649		-
EA	Blade Elastic Axis	750-849	-	- Anna Caracteria
QE0	Blade Edgewise Steady Deflection			
QFO QEOP	Blade Flatwise Steady Deflection Derivative of QEO with respect		-	
QLOF	to R		-	
QFOP	Derivative of QFO with respect	•	_	
	to R			
DT	Elemental Thrust		-	3d
DH	Elemental Drag		-	
DM	Elemental Pitching Moment		-	
D	Derivative with Respect to		_	
D(UT) D	Tangential Velocity Derivative with Respect to			
D(UP)	Vertical Velocity		. -	, posterior
D	Derivative with Respect to		_	
<u>D(θT)</u>	Angle-of-Attack			
CL	Coefficient of Lift	2750-3649	aine -	3e
CD	Coefficient of Drag	1850-2749	1	
CM	Coefficient of Pitching Moment	3650-4548	-	
<u>D</u>	Derivative with Respect to		=	and the second s
DA D	Angle-of-Attack Derivative with Respect to Mach			
DM DM	Number		-	
0 STRUC- TURAL	Structural Twist	450-549	-	e de la constanta de la consta
θ AERO- DYNAMIC	Aerodynamic Twist	350-449		000000000000000000000000000000000000000
Up	Hover Inflow Velocity			
UΤ	Tangential Velocity		-	
U	Total Velocity	*	-	***
Ø ALPHA	Inflow Angle Angle-of-Attack	•	-	
PHE(I)	Edgewise Part of i th Blade Bend-		_	3f
(- /	ing Mode		-	
PHF(I)	Flatwise Part of i th Blade Bend-	-	-	
	ing Mode			
PHEP(I)	Edgewise Slope Part of i th Blade	-	-	
	Bending Mode			
PHFP(I)	Flatwise Slope Part of i th Blade	-	-	
Como figura de referencia professa apprilación es consecuciones es con	Bending Mode			

The rotor blade radial distributions of edgewise, flatwise and torsional mass moments of inertia, mass, and edgewise and flatwise area moments of inertia are shown in Figure 3g. Care must be exercised in the input of these quantities to make sure that the sum of the blade segments equals the blade radius (location 6).

It either rigid blade flapping or inplane motion is used in the rotor analysis, then the rotor blade flapping mass, first and second moments of inertia and the blade lag frequency are printed out as can be seen in Figure 3h. In this figure are also shown calculations of the blade bending mode generalized masses (defined as the blade mass times the sum of the squares of the flatwise and edgewise components) and of other blade parameters.

The total number of degrees-of-freedom used in the rotor analysis is indicated in Figure 3h. The individual degrees-of-freedoms are identified by integers according to the schedule given below.

Number	Degree-of-Freedom	<u>Motion</u>
1-4 5-6 7 8 9-16 17-20 21-22 23-24	Blade Bending Modes (up to 4) Blade Torsional Modes (up to 2) Blade Rigid Body Flapping Blade Rigid Body Lead-Lag Blade Bending Modes Blade Torsional Modes Blade Rigid Body Flapping Blade Rigid Body Lead-Lag	Symmetric Cyclic
25-29	Fixed System Modes (Fixed at 5)	-

Thus, for the example in Figure 3h, it is seen that two blade bending modes, rigid body flapping and lead-lag and five fixed system modes are employed for a total of 17 degrees-of-freedom.

The maximum number of rotor/fixed system degrees-of-freedom is 29 (8 blade modes times 3 plus 5 fixed system modes).

A sample output matrix is presented in Figure 4. For this case, location 108 was set to 1. to yield the printout of the compressed (17 X 17) rotor/fixed system matrices. The complete 29 X 29 matrices can be displayed if location 107 is set to 1. The order of the elements in each column follows the schedule shown above. For example, the fourth element in the second row corresponds to the lead-lag symmetric stiffness contribution to the second blade bending mode symmetric equation of motion.

The compressed matrices include rotor aerodynamic contributions. They are coupled directly to the bifilar analysis. If no rotor coupling is desired, then the compressed matrices are stored for future use.

4.2 Bifilar Analysis Output

Typical output formats presenting results from the bifilar analysis are shown in Figures 5 through 8. The output parameters from Figures 5a through 5k are common for both linear and non-linear bifilar analyses. The final linear analysis results are presented in Figure 6 while the non-linear results can be seen in Figures 7 and 8.

Figure 5a shows the number of degrees-of-freedom utilized in a given computer run, the number of aircraft stations where the response is calculated and the printout options requested. For the example shown, it is seen that nine fixed system modes, one fixed system absorber and one kind each of inplane and vertical bifilars are requested. In addition, rotor coupling is employed and the response of four aircraft stations is to be analyzed. All printout switches have been activated (set at 1.0) to show examples of the output generated.

The bifilar analysis starts off with the fixed system degrees-of-freedom. Then, it expands the fixed system stiffness, damping and mass matrices to include in sequence the contributions from the rotor, fixed system absorbers, linear inplane bifilars and finally the linear vertical bifilars. Then, either a forced response or a time-history solution is calculated depending on the input to location 18. The build-up of the degrees-of-freedom is shown in Figures 5b through 5k for the stiffness matrix only. The damping and mass matrices are handled in an identical manner.

The basic fixed system stiffness matrix is presented in Figure 5b. It is seen that for this example the stiffness matrix is a square diagonal matrix of order 9. This printout is governed by location 1490.

The rotor/fixed system stiffness matrix to be coupled with the bifilar analysis is shown in Figure 5c and d and is of order 18. This matrix is basically the same as that from Figure 4 except that now the fixed system degrees-of-freedom appear first and include an extra equation corresponding to the yaw degree-of-freedom (which is not present in the rotor aeroelastic analysis). Consequently, the total number of degrees-of-freedom is 18. This printout option is controlled by location 17.

Every time a new system component is added, the printout shown in Figure 5e is automatically obtained. It shows what the present number of degrees-of-freedom (d.o.f.) is (for this example, 9 fixed system d.o.f.), the number to be added (12 rotor d.o.f.) and the final system d.o.f. (a total of 21 d.o.f.).

The combined fixed system/rotor stiffness matrix is displayed in Figure 5f. Only the first nine equations are shown here for brevity. This output is obtained if location 1491 is set to 1.0.

Next, the fixed system/rotor coupled system is expanded to include the contribution of the fixed system absorber. In this example, only one absorber is used and thus the number of d.o.f. becomes 22, as can be seen in Figure 5g. Location 1492 controls this printout option.

If linear inplane bifilar pendulums are used (see location 1), then the fixed system/bifilar coupled matrices (mass, damping and stiffness) can be obtained for each kind of bifilar (see loc. 1495). The output matrices in all cases are square matrices of order 9. The first 6 d.o.f. correspond to the hub motions (x, y, z, θ_X , θ_Y and θ_Z respectively) and the next three to the inplane bifilar symmetric and two cyclic modes. In Figure 5h, the coupled stiffness (QQK) matrix is presented.

The system matrices are now expanded to include the contribution of the inplane bifilar pendulums. The stiffness matrix of the fixed system/rotor/fixed system absorber/inplane bifilar coupled system can be seen in Figure 5i. Since only one kind of inplane bifilar is used in this example, the final number of d.o.f. is increased by 3 for a total of 25. This output is generated if location 1493 is set to 1.

If linear vertical bifilar pendulums are employed in the analysis (see loc. 12), the corresponding fixed system/vertical bifilar matrices can be displayed (see loc. 1496) as seen in Figure 5j. The format is the same as that for the inplane bifilars.

Now the vertical bifilar d.o.f. are added to the system. The final stiffness matrix for this example is shown in Figure 5k. The total d.o.f. to be analyzed is 28. This output format is controlled through location 1494.

The results of the linear bifilar analysis are presented in Figure 6. The cosine and sine components of the generalized forces appearing near the top of Figure 6a are obtained by multiplication of the hub forces/moments vectors (see loc 110-119 for the cosine component and loc 120-129 for the sine component) by the transpose of the rotor hub transfer matrix (located in loc. 450-549). The units are lbs and inch-lbs.

The "GAMMAS" printed out in Figure 6a are the generalized coordinates of the rotor/fixed system absorber/bifilar coupled system and are obtained from the forced response solution. First, the cosine component for all d.o.f. is printed out and then the sine component. For this example, the total number of d.o.f. of the rotor, the fixed system absorber and the inplane and vertical bifilars equals 19. Thus, 38 values of "GAMMAS" are printed out; the printout switch is location 1497. The units are in inch for the fixed system absorber and non-dimensional for the rotor and bifilars.

The "GAMMAS" are sorted out according to the system components present and printed out accordingly, as shown in Figure 6a and 6b. The calculated amplitudes are in inch for the fixed system absorber and in degrees for both inplane and vertical bifilar pendulums, all phase angles are shown in degrees. The method used to calculate the bifilar amplitudes is shown below.

OUTPUT FORMAT

	Cosine	<u>Sine</u>	<u>Amplitude</u>	<u>Phase</u>
Symmetric Equation Cyclic Equation - sine Cyclic Equation - cosine	A _{OC} A _{SC} A _C C	A _{CS} A _{CS}	A _N A _{N-1} A _{N+1}	PHIN PHIN-1 PHIN+1
$A_N = A_{0C}^2 + A_{0S}^2 * 57.30$				
$A_{N-1} = A_1^2 + A_2^2 * 57.30/N$				
$A_{N+1} = A_3^2 + A_4^2 * 57.30/N$	IB where A	$A^3 = A^{CC}$	- A _{SS} & A ₄	$= A_{CS} + A_{SC}$
and NB = number of bifilar p	endulums			

The input frequencies are listed out in Figure 6b; the units are in Hz.

The forcing frequency in Hz is obtained by multiplying the forcing frequency in cycles/rev (loc 3) by the rotor speed (loc 7) and dividing by 60.

The conversion factor to g's is obtained by dividing the square of the forcing frequency in rad/sec by the factor 386.40.

The fixed system generalized coordinates are also shown in Figure 6b. The units are inch. They are utilized to calculate the dynamic response of the aircraft stations and of the rotor head which are shown in Figures 6b through 6d. As indicated in the printout, the aircraft and hub response is in g's.

Sample results from the time history solution when non-linear inplane bifilar absorbers are employed (loc 18 is 1.) are printed in Figures 7 and 8. If the total number of degrees-of-freedom exceeds 72, then a message will be printed out to that effect and the non-linear analysis proceeds to the next case to be analyzed.

In Figure 7a, the top line lists out the different components degrees-of-freedom requested in a specific computer run. For the example shown, the total number of d.o.f. is 29 which is obtained as follows:

System Component

		<u>D.O.F.</u>
1. 2. 3.	Fixed system modes (NF) Rotor d.o.f. (KROTOR) Fixed system absorber (NFABS)	9 12 1
4. 5. 6.	Kinds of (linear) inplane bifilars (OX3) Kinds of vertical bifilar (1X3) Number of non-linear inplane bifilars	0 3 4
		29

The time history solution proceeds at first to collect all the acceleration terms on the left hand side of the equations of motion. The right hand side contains the stiffness and damping terms and the forcing functions. Successive integrations of the accelerations yield the velocity and displacement vectors at the next time increment. Then, the system accelerations are computed again and the procedure continues until a converged time history is obtained or the maximum azimuthal position (specified in location 1762) is reached.

The output formats presented in Figures 7a through 7e are for zero azimuth. The initial right hand side (r.h.s.) terms are displayed in Figure 7a. They are all zero to start since no initial conditions of the state variables displacements and velocities have been located in the input locations 1780 through 1939. This printout appears for azimuth positions up to 3 degrees.

The next printout shown in Figure 7a is that of the left-hand-side mass matrix whose order is the sum of the six hub d.o.f. and the number of non-linear inplane bifilars (loc. 1763) which for this example is four. The bifilar force vector is also listed out in this figure. Small values appear in this vector due to coupling terms between the fixed system and the bifilar pendulums. These outputs are presented for azimuth positions up to 5 degrees.

The rotor head mode shapes appear in Figure 7b. This matrix is an image of the input in locations 450 through 549. It is shwon only for azimuth positions up to 2 degrees.

The next printout in Figure 7b is that of the "Expanded Bifilar Mass Matrix" whose order is the sum of the number of fixed system modes (loc 9) and the non-linear bifilars (loc 1763). Similarly, the "Expanded Bifilar Force Vector" is printed out in Figure 7c. Both output formats are generated for azimuth angles up to 5 degrees.

The contributions of the remaining system components are now added to the fixed system/non-linear inplane bifilar system. The resulting mass matrix and force vector can be seen in Figures 7d and 7e respectively. The final matrix order is 29, as previously stated in Figure 7a. These printouts are obtained for azimuth angles up to 15 degrees.

The solution vector of the state variables and the non-linear bifilar displacements and velocities at zero azimuth is shown in Figure 7e. It is printed out for azimuth angles up to 30 degrees. This vector is now used to calculate the right-hand-side terms at the next azimuth position (as defined in location 1761) which are displayed at the bottom of Figure 7e.

The time history solution proceeds around the rotor azimuth until either the convergence criterion set on the bifilar motions is satisfied or the maximum azimuth value (loaded in location 1762) is reached. At the end of each rotor revolution, bifilar displacements and hub motions are printed out as exhibited in Figure 7f. For the example shown, 16 rotor revolutions were necessary before the convergence criterion was met, i.e. the angular displacements of the first two bifilars (G1 and G2) for two successive revolutions must be within .002 radian (or .1146 degree).

The rotor/bifilar analysis then proceeds to calculate the harmonic response of the non-linear bifilar pendulums displacements, the hub six degrees-of-freedom (the order is x, y, z, $\theta_{\rm X}$, $\theta_{\rm y}$ and $\theta_{\rm z}$) and the aircraft station(s) linear motions (x, y and z), as can be seen in Figures 8a and 8b. The pendulum output is in degrees while the hub and A/C station(s) output is in g's. All phase angles are in degrees. The four rows of output describing the hub and A/C response are respectively the cosine and sine components, the total amplitude and phase angle. For the example shown, the bifilar motions are about 9.8 degrees each; the longitudinal (x) hub response is .13864 g's.

The final output format of the non-linear analysis results consists of the initial values of bifilar, hub and state variables displacements and velocities. These results can be loaded into locations 1720 through 1939 and will be used as initial conditions for the subsequent computer run provided location 1498 is set to 1.0.

Additional information can be printed out if the control switches in locations 10 and 15 are activated. This is only needed if debugging of the bifilar analysis calculations is desired.

SECTION 5

TEST CASES RESULTS

5.1 Test Cases Description

The rotor/bifilar coupled analysis has been executed for the following four test cases:

- Case 1. Includes rotor and uses linear bifilar analysis.
- Case 2. Includes rotor and uses non-linear bifilar analysis.
- Case 3. Doesn't include rotor and uses linear bifilar analysis.
- Case 4. Doesn't include rotor and uses non-linear bifilar analysis.

These cases test the major program logic paths.

For each case, the component degrees-of-freedom utilized are listed in the chart below.

COMPONENT D.O.F.

Test Case	Rotor Blade	Fixed System	Fixed Absorber	Linear Inplane	Bifilar Vertical	Non-Linear Bifilars	Total D.O.F.
1	12	9	1	3	3	0	28
2	12	9	1	0	3	. 4	29
3	0	9	1	3	3	0	16
4	0	9	1	0	3	.4	17

The rotor degrees-of-freedom include two blade bending modes and rigid body flapping and lead-lag motion. Only one kind of inplane and vertical linear bifilars is used in the test cases. However, the analysis has been checked out for cases utilizing several kinds of bifilar pendulums. The inplane bifilars are tuned to 4 per rev.

5.2 Job Control Language

The Job Control Language (JCL) needed to execute the coupled program on the IBM 370/169 computer system is presented in Appendix A. This JCL must be modified for use on the NASA CDC computer system. A brief description of the JCL setup is discussed below.

Card <u>Number</u>	<u>Description</u>
1	Describes job name and characteristics (class, time, etc.).
2	Executes program module E90BCFIN.
3	Locates program module in ET473.SEBBY.LOAD.
4	Reads input data from ET473.BIFILAR.DATA (NASARUN) using Unit 5.
5	Provides paper output using Unit 6.
6	Provides punched cards output using Unit 7.
7	Stores calculated data internally in Unit 8.
8	Stores input data for first case in Unit 11 to be used for
	successive cases.
9 .	Ends JCL setup.

5.3 Test Cases Input Data

The input data needed to run the four test cases is listed in Appendix ${\sf B.}$

The input format which must be followed to run multiple cases is described in Table 2 below.

TABLE 2. Program Multiple Cases Setup

Data <u>Block</u>	Input Data Description	Case <u>Number</u>
1 2	Rotor blade data (loc. 1-4549)	1
	Last rotor blade data card (minus sign in column 1)	
3	Title for rotor blade data	
4	Title for bifilar data	
4 5 6	Bifilar data (loc. 1-2199)	
6	Last bifilar data card (loc 2200 = 0 not last case)	
7	Rotor blade data	2 (last)
8	Last rotor blade data card (minus sign in column 1)	
9	Bifilar data	
10	Last bifilar data card (loc 2200 = 1 last case)	\downarrow

The format above is shown for two cases only for brevity. Data blocks 7 through 10 are repeated for each case.

If the first case does not use rotor data, then the data blocks numbered 1 through 3 above are replaced by a single card as follows:

-1 110 0.

5.4 Test Cases Output

The results of the rotor/bifilar coupled program for the four test cases are presented in Appendix C. Only the important results are shown in the Appendix to minimize the size of this report (the actual run consisted of 165 pages of output with only the most important printout switches being activated).

Some important results from the bifilar analysis are summarized in the Table 3 below.

Test		ne Bifilar			Hub Res			-1 (7)
Case Number		ponse Phase (deg)	Ampl. (g's)	dinal (X) Phase (deg)	Latera Ampl. (g's)	1 (Y) Phase (deg)	Vertic Ampl. (g's)	al (Z) Phase (deg)
1	9.29	-77	.134	113	.094	178	.006	132
2	1. 9.76 2. 9.77 3. 9.80 4. 9.80	96 -174 -84 6	.139	-84	.100	-20	.008	-53
3	9.52	-86	.184	113	.081	137	.010	46
4	9.57 9.58 9.63 9.62	88 177 -93 -2	.193	-79	.086	-56	.010	-134

TABLE 3. Bifilar Analysis Test Cases Results

For all test cases, the input force is a 4 per rev fixed system force with lateral sine and longitudinal cosine components of 500 pounds. For the non-linear bifilar analysis results, the response of each of the four inplane bifilars is shown in the table above (cases 2 and 4).

5.5 Test Cases Computer Time

The computer total running time for the four test cases was 8 minutes and 43 seconds. The break-down in computer time per case is shown in the following table.

Test Case	Number	Bifilar	Computer	r Time
Number	of D.O.F.	Analysis	Minutes	Seconds
1	28	Linear	0	25
2	29	Non-linear	7	07
3	16	Linear	0	03
4	17	Non-linear	1	08
	and procedurate state of the control	Total	8	43

From the table above, a comparison between cases 1 and 2 and between cases 3 and 4 reveals that the time history analysis requires considerable greater computer time for a complete converged solution than the linear analysis. Also, the computer running time increases tremendously as the number of system degrees-of-freedom is increased when comparing cases 1 and 3 and 2 and 4.

SECTION 6 OVERALL PROGRAM STRUCTURE

The rotor/bifilar program is basically made up of two parts: the rotor aeroelastic analysis and the fixed system/fixed absorber/bifilar pendulums analysis. The bifilar anlaysis can be executed with and without coupling with the rotor analysis while the opposite is not possible. In addition, the bifilar portion of the program can use either a forced response solution for linear inplane bifilar pendulums or a time history solution for non-linear inplane bifilars. The main purpose of the rotor aeroelastic analysis is to provide the rotor blade stiffness, damping and mass matrices for coupling with the bifilar analysis.

6.1 Segmentation Structure

Due to the large size of the coupled program, it was necessary to implement a segmentation structure to permit operation within a 64K (decimal) for CDC computer use. A basic breakdown of the 10 control segments needed is shown in Table 4 below and in the schematic of Figure 9.

TABLE 4. Segmentation Structure Description

Segment Number	Leading Fortran <u>Routine</u>	Number of Segment Routines	Segment Description
1	SHAKIT	4	Controls overall program logic and specifically the rotor
2	PRELIM	34	analysis program flow. Reads rotor input, initializes data and performs many basic rotor calculations.
3	DYNMAT	12	Calculates rotor dynamic matrices.
4	AERMAT	17	Calculates rotor aerodynamic
5	EIGER	2	matrices. Combines dynamic and aero- dynamic rotor matrices, com- presses and links them to the
6	MAINSV	3	bifilar analysis. Controls bifilar analysis
7	SYSCTL	6	program flow. Calculates contributions from fixed system modes, fixed absorber, inplane and vertical linear bifilar and couples rotor
8	HUBIMP	1	matrices. Computes rotor hub impedance and transfer matrices.
9	СМРИТЕ	4	Controls generalized forces calculations and solves for the forced response for the linear bifilar analysis option.

10 NLBIF 9 Performs time-history solution for the non-linear bifilar analysis option.

Total = 92

A total of 92 Fortran routines have been developed for this program: 69 of them comprise the rotor analysis portion while 23 make up the bifilar analysis portion.

From the schematic presented in Figure 9, it seen that the rotor aeroelastic analysis is performed in segments 1 through 5 while the bifilar analysis is handled by segments 6 through 10. There is no lateral transfer of data between any two segments; data can only be transferred in a vertical sense to segment 1 for the rotor portion and to segments 1 and 6 for the bifilar portion.

Table 5 below lists in alphabetical order the Fortran sub-routines and the common blocks needed for each segment.

TABLE 5. Segmentation Structure Routines and COMMON Blocks

Segment Number	<u>Fortran</u>	Subrouti	COMMON Block Name		
1	SHAKIT INTEG LOADIT QTFG			DYNINP EOF6 INDAT INEIG INEIGN	LAGDAM NIMIC PRNTSW TMDS
	PRELIM BLIN4 ELI ELO EXTEND E159X FILL FOLL FREQUN FULL GMPRDD	MATEO MATF MATR MIND MISC MODES MSHAPE ORTHOG OVUN PFMULT PICK	PINT POUT PRODM PROUT REMOVE ROOTX SECAER SIMLIN SKIPLN SORTAB STDEFL	CONT DAT EMATI EMATO FMAT FREQ PHTNO PMAT PRAM1 TORFIN WORKA	
3 4 4	MATEI DYNMAT BLELPD DISCON DISINT AERMAT AERINT AERIN1 AERIN2 AERIN3 AERIN4	DMATEX DMDMAT DMMMAT DMSMAT AERIN5 AERIN6 AERIN7 AERIN8 AERLST AEROI	DYNINT DYNIN1 DYNIN2 DYNLST AEROII AMATEX AMDMAT AMSMAT BLELPA	DYNOUT NAMIC AERO1 AERO2 AERO3 AERO4 AERO5 CDCAER	

Segment Number	Fortran	Subroutine Name	COMMON Bloc	k Name
5	EIGER			
↓	COMPRSS			
6 .	MAINSV		NDOF	TOTMAT
	INCOND		NLDAT1	XFRDAT
. V	INPUTY		PRSWTH	***************************************
7	SYSCTL			sicion
	ADDOFR			
	FIXABS			o contraction of the contraction
	FIXSYS		ria -	
	LINBIF			
↓	LVBIF			decommen
Ψ . 8	HUBIMP			as capped
9	CMPUTE			
Ī	FORCER			SACCOPPRE
	GENFOR			
V	OUTPUT			
ıď	NLBIF	HARMON	HARM	reproved
1	BIFEXP	INTEQ	NLDAT2	
	BIFILR	OUT	NEDAIZ	
	COMBIN	RHS		
V	CONVER			No.

All the Fortran sub-routines listed above except four are computer independent. The computer dependent routines are: SHAKIT (segment 1), LOADIT (segment 1), PRELIM (segment 2) and MAINSV (segment 6). This is due to CDC computer requirements for identification of the main routine, file read error and end of file transfers and word size definition for alpha-numeric read statements. The program coding allows the programmer to convert easily to the IBM 370/168 computer system by commenting out the appropriate block(s) of statements.

6.2 Flow Diagrams

Computer logic flow diagrams are presented in Figures 10 through 16 for the 10 segments. A summary of the flow charts is provided in the table below.

<u>Figure Number</u>	Flow Chart Description	Segment Number(s)
10	Main Program Flow Chart	1 & 5
11.	"PRELIM" Flow Chart	2
12	"MODES" Flow Chart	2
13	"DYNMAT" Flow chart	3
14	"AERMAT" Flow Chart	4
15	Bifilar Analysis Flow Chart	6 & 8
16a	"SYSCTL" Flow Chart	7
16b	"CMPUTE" Flow Chart	9
16c	"NLBIF" Flow Chart	10

It should be noted that "IMSL" routines are needed for the calculations performed in "HUBIMP" and "NLBIF". Table 6 below lists the 10 "IMSL" routines used in the bifilar analysis portion of the coupled program:

TABLE 6. IMSL Routines

No.	IMSL Routine Name
1	LEQT2F
2	LINV2F
3	LUDATF
4	LUELMF
5	LUREFF
6	UERTST
7 .	UGETIO
8	VXADD
9	VXMUL
10	VXST0

These routines must be supplied by the government for successfull operation of the rotor/bifilar coupled program.

6.3 "COMMON" Blocks

The "COMMON" blocks used in the rotor/bifilar analysis are presented in Figure 17 as they appear in each Fortran sub-routine. Both routines and "COMMON" blocks are listed alphabetically for easy reference.

SECTION 7

SUBROUTINE DESCRIPTIONS

The Fortran subroutines needed to execute the rotor/bifilar coupled program are described in detail in this section. For each routine, the following information is provided, where applicable:

- 1. Name
- 2. Purpose
- 3. Method
- 4. Usage
- 5. Subroutines Called
- 6. Error Returns
- 7. Restrictions

In addition, an alphabetical listing of the routines and the corresponding page numbers are shown in Table 7 below for easy reference.

TABLE 7. Program Subroutines Listing

No.	<u>Name</u>	Page	No.	<u>Name</u>	Page	No.	Name	<u>Page</u>	<u>No.</u>	<u>Name</u>	<u>Page</u>
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	ADDOFR AERIN1 AERIN2 AERIN3 AERIN4 AERIN5 AERIN6 AERIN7 AERIN6 AERIN7 AERIN8 AERIN7 AERIN8 AERIN7 AERIN8 AERIN7 AERIN8 AERIN8 AERIN7 AERIN8 AERIN8 AERIN8 AERIN7 AERIN8 AE		24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43	CMPUTE COMBIN CONVER DISCON DISINT DMATEX DMDMAT DMMMAT DYNINT DYNINT DYNINT DYNINT DYNINT EIGER ELI ELO EXTEND E159X FILL		47 48 49 50 51 52 53 54 55 56 57 58 60 61 62 63 64 65 66	FORCER FREQUN FULL GENFOR GMPRDD HARMON HUBIMP INCOND INPUTV INTEG INTEQ LINBIF LOADIT LVBIF MAINSV MATEI MATEO MATF MATR MIND		70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88	NLBIF ORTHOG OUT OUTPUT OVUN PFMULT PICK PINT POUT PRELIM PRODM PROUT QTFG REMOVE RHS ROOTX SECAER SHAKIT SIMLIN SKIPLIN	131 132 133 134 135 136 138 139 140 141 144 145 146 147 148 149 150 151 152 153
21 22 23	BLELPD BLIN4 CMPRSS		44 45 46	FIXABS FIXSYS FOLL		67 68 69	MISC MODES MSHAPE		90 91 92	SORTAB STDEFL SYSCTL	154 155 157

ADDOFR

PURPOSE:

To add degrees-of-freedom to the mass, damping and stiffness system matrices in the bifilar analysis.

METHOD:

The new matrices to be added of order NL X NL are split up in four parts:

An upper diagonal matrix of order (NL-NA)X(NL-NA)

2. A lower diagonal matrix of order NA X NA

3. An upper off diagonal matrix of order (NL-NA) X NA

4. A lower off diagonal matrix of order NA X (NL-NA)

The lower diagonal matrices are added to the original matrices of order NP X NP, which now become of order (NP + NA) X (NP + NA). The upper off diagonal matrix is pre-multiplied by the fixed system transfer matrix XPH (locations 450-549) while the lower off diagonal matrix is post-multiplied by XPH. The upper diagonal matrix is pre-multiplied and post-multiplied by XPH.

USAGE:

CALL ADDOFR (NL, NA, NP)

NL = Order of matrices to be added

NA = Number of degrees-of-freedom to be added

NP = Present order of matrices (after ADDOFR,

order of matrices is NP + NA)

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

AERINT

PURPOSE:

To set initial values of all blade aerodynamic integrals to zero and to control the calculation of the aerodynamic integrals needed to construct the aerodynamic damping

and stiffness matrices.

METHOD:

Aerodynamic integrals independent of the number of bending modes are calculated by calls of AERIN1 and AERIN7 for lift, AERIN3 and AERIN8 for drag, and AERIN4 for pitching moment. Integrals involving bending mode dependent functions are calculated in AERIN2, AERIN5 and AERIN6 for lift, drag and pitching moment

respectively.

USAGE:

CALL AERINT

SUBROUTINES

CALLED:

AERIN1, AERIN2, AERIN3, AERIN4, AERIN5, AERIN6, AERIN7,

AERIN8

ERROR RETURNS:

None

RESTRICTIONS:

Due to computer storage restrictions, the aerodynamic integrals had to be calculated in 8 separate routines,

i.e. AERIN1 through AERIN8.

AERIN1

PURPOSE:

To calculate the aerodynamic integrals which contain thrust derivatives and are independent of the number

of blade bending modes.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions, and are referred to as unsubscripted ATK and AT1K integrals.

Since all the integrals involve thrust derivatives, the upper limit of integration is the blade radius

multiplied by the tip loss factor.

USAGE:

CALL AERIN1

SUBROUTINES

CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERIN2

PURPOSE:

To calculate the aerodynamic integrals which contain bending mode dependent functions and thrust derivatives.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions. They are referred to as ATII and AT2I for doubly subscripted integrals and ATJ, AT3J, AT3J for singly subscripted integrals. Since all the integrals involve thrust derivatives, the upper limit of integration is the blade radius multiplied by the tip loss factor.

USAGE:

CALL AERIN2

SUBROUTINES

CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERIN3

PURPOSE:

To calculate the aerodynamic integrals which contain drag derivatives and are independent of the number of

blade bending modes.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions, and are referred to as un-

subscripted ADK and AD1K integrals.

Since all the integrals involve drag derivatives,

they are computed over the whole blade.

USAGE:

CALL AERIN3

SUBROUTINES CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERIN4

PURPOSE:

To calculate the aerodynamic integrals which contain pitching moment derivatives and are independent of the number of blade bending modes.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions, and are referred to as un-

subscripted AM1K, AM2K, AM3K integrals.

Since all the integrals involve pitching moment derivatives, the upper limit of integration is the blade

radius multiplied by the tip loss factor.

USAGE:

CALL AERIN4

SUBROUTINES

CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERIN5

PURPOSE:

To calculate the aerodynamic integrals which contain bending mode dependent functions and drag derivatives.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions. They are referred to as AD1I and AD2I for doubly subscripted integrals and ADJ, AD1J, AD2J and AD3J for singly subscripted integrals.

Since all the integrals involve drag derivatives, they

are computed over the whole blade.

USAGE:

CALL AERIN5

SUBROUTINES CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERIN6

PURPOSE:

To calculate the aerodynamic integrals which contain one bending mode dependent functions and pitching

moment derivatives.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions, and are referred to as singly subscripted AM1J and AM2J integrals. Since all the integrals involve pitching moment derivatives, the upper limit of integration is the blade radius multiplied by

the tip loss factor.

USAGE:

CALL AERIN6

SUBROUTINES

AEROII, AEROI

CALLED:

ERROR RETURNS:

None

RESTRICTIONS:

AERIN7

PURPOSE:

To calculate the aerodynamic integrals which contain thrust derivatives and are independent of the number

of blade bending modes.

METHOD:

These integrals are formed in AEROI from the product

of 5 radial functions, and are referred to as unsubscripted

AT2K and AT3K integrals.

Since all the integrals involve thrust derivatives, the upper limit of integration is the blade radius multiplied

by the tip loss factor.

USAGE:

CALL AERIN7

SUBROUTINES

CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERIN8

PURPOSE:

To calculate the aerodynamic integrals which contain drag derivatives and are independent of the number of

bending modes.

METHOD:

These integrals are formed in AEROI from the product of 5 radial functions, and are referred to as unsubscripted AD2K and AD3K integrals. Since all the integrals involve drag derivatives, they are calculated over the whole

blade.

USAGE:

CALL AERIN8

SUBROUTINES

CALLED:

AEROII, AEROI

ERROR RETURNS:

None

RESTRICTIONS:

AERLST

PURPOSE:

To print the aerodynamic integrals.

METHOD:

If the print option is set at 3 or 4, then the integrals are printed. Otherwise control is returned to AERMAT $\,$

with no integrals printed.

Only those integrals calculated are printed.

USAGE:

CALL AERLST

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

AERMAT

PURPOSE:

To control the calculation of the aerodynamic damping

and stiffness matrices.

METHOD:

The aerodynamic integrals needed to calculate the matrices are evaluated in AERINT, stored in COMMON blocks AERO1 through AERO5, and printed out by AERLST. AERMAT then makes calls to AMDMAT to calculate the damping matrix, and to AMSMAT to calculate the stiffness matrix. Then, it extends the matrices to include blade torsional bending mode terms in AMATEX and calls BLELPA to calculate elastic torsional contributions.

USAGE:

CALL AERMAT

SUBROUTINES

CALLED:

AERINT, AERLST, AMDMAT, AMSMAT, AMATEX, BLELPA

ERROR RETURNS:

None

RESTRICTIONS:

AEROI

PURPOSE:

To calculate the integral of the function y = F1(R)*F2(R)*F3(R)*F4(R)*F5(R) in the interval (r1, r2).

METHOD:

The 5 radial functions are multiplied together at each radial station specified. It should be noted that the second argument in the AEROI calling sequence is designated complex and corresponds to an aerodynamic derivative function. The integral is evaluated in two parts, real and imaginary, by calls to INTEG. If there are no unsteady aerodynamic corrections, then the imaginary part of the integral is set to zero.

USAGE:

CALL AEROI (F1, F2, F3, F4, F5, ANS)

F1, F3, F4, F5 = Real functions defined at the radii in R from AEROII. One or more may be equal to 1.0 at every R.

F2

= Complex function defined at the radii in R. If no unsteady aerodynamic correction has been applied, the imaginary part will be zero.

ANS

= The complex integral of the product of F1 through F5. If no unsteady aerodynamic corrections have been applied, then the imaginary part will be zero.

SUBROUTINES CALLED:

INTEG

ERROR RETURNS:

None

RESTRICTIONS:

AEROII

PURPOSE:

To set up calculations of the integral of the function y = a(R)*b(R)*c(R)*d(R)*e(R) over the interval (r1,r2).

METHOD:

This routine sets the radial values where the functions are defined, the limits of integration, the number of subdivisions to be used in the trapezoidal rule integration method and the switches for unsteady aerodynamics.

Subsequent calls to AEROI supply the 5 functions whose product is to be integrated.

USAGE:

CALL AEROII (R, N, RL, RU, K, CIR, CIRN)

R = Array of radii at which the functions are defined.

N = The number of points in R and in each function array.

RL = The lower limit of integration.

RU = The upper limit of integration.

K = The number of subdivisions to be used in performing the integration by the trapezoidal rule.

CIR = 1 No circulatory unsteady aerodynamics used.

CIRN = 1 No noncirculatory unsteady aerodynamics used.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

- 1. N must be equal or less than 25.
- 2. CIR and CIRN have been set to 1 for no unsteady aerodynamics.

AMATEX

PURPOSE:

To expand the aerodynamic matrices to include the blade

elastic torsional mode.

METHOD:

The original aerodynamic damping (AMD) and stiffness (AMS) matrices are increased by 3 rows and columns and redefined as AMDN and AMSN to accomodate one collective and two cyclic modes associated with the

blade elastic torsional mode.

USAGE:

CALL AMATEX

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

The matrices are limited to 30×30 .

AMDMAT

PURPOSE:

To calculate the aerodynamic damping matrix.

METHOD:

The matrix is calculated from the expressions given in Reference 1 using the aerodynamic integrals calculated in AERINT.

USAGE:

CALL AMDMAT

SUBROUTINES CALLED:

ERROR RETURNS:

None

None

RESTRICTIONS:

AMSMAT

PURPOSE:

To calculate the aerodynamic stiffness matrix.

METHOD:

The elements are calculated from the expressions given in Reference 1 using the aerodynamic integrals calculated in AERINT.

USAGE:

CALL AMSMT

SUBROUTINES

None

CALLED:

ERROR RETURNS: None

RESTRICTIONS:

86844

NAME:

BIFEXP

PURPOSE:

To transfer the non-linear bifilar mass matrix and the bifilar and rotor hub force vector to fixed system coordinates.

METHOD:

The bifilar mass (square matrix of order 6+NBIF) and the force vector (of order 6+NBIF) are transferred to the fixed system coordinates by proper multiplications with the fixed system mode shapes vector (loc. 450-549). The final expanded mass matrix and force vector have the dimensions of NF + NBIF. The method used is similar to that discussed in routine ADDOFR. expanded mass and force vector are passed through labelled COMMON/NLDAT2.

They are printed out for azimuth positions up to 5 degrees. The fixed system mode shapes vector is printed out for azimuths up to 2 degrees.

USAGE:

CALL BIFEXP (NRHS, NF)

NRHS = Total number of non-linear bifilars plus 6

(maximum is 18).

NF = Number of fixed system modes (maximum is 16).

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

Expanded matrix and force vector cannot have dimensions greater than 28.

BIFILR

PURPOSE:

To calculate the non-linear bifilar mass matrix and the bifilar and rotor hub force vector.

METHOD:

For the time history solution, the bifilar acceleration terms are left on the left-hand-side of the equations of motion while the r.h.s. contains the bifilar damping and stiffness terms and the input hub forces. The bifilar mass matrix, S (dimensioned 6+NBIF), is calculated and stored in labelled COMMON/INEIGN. Then, the bifilar damping and stiffness terms are used to develop the r.h.s. vector, T (dimensioned 6+NBIF). Next, the rotor hub forces, loaded in locations 1600 through 1719, are evaluated and added to the bifilar contributions in vector T.

The hub forces are added to the system gradually according to the ramp factor (location 1760) and the azimuth position. The vector T is passed through labelled COMMON/NLDAT2.

The order of the degrees-of-freedom in this routine is: 6 fixed system d.o.f. $(x, y, z, \theta_X, \theta_Y, \theta_Z)$ and non-linear bifilars d.o.f. (NBIF-location 1763). Thus, the maximum number of d.o.f. is 18.

For azimuth positions up to 5 degrees, the mass matrix and the force vector are printed out.

USAGE:

CALL BIFILR (NREV)

NREV = Revolution number-location 1762 divided by 360.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

Number of input harmonics of rotor hub forces is limited to 10.

BLELPA

PURPOSE:

To calculate the blade elastic pitch aerodynamic

contributions.

METHOD:

The aerodynamic damping and stiffness matrix elements are calculated using the appropriate expressions for

blade pitch in Reference 1. All the terms are multiplied by the torsional mode shape, PH(r), which is a function of blade radius, except the blade pitch terms which are multiplied by the square

of the mode shape.

USAGE:

CALL BLELPA

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

BLELPD

PURPOSE:

To calculate the blade elastic pitch dynamic

contributions.

METHOD:

The dynamic mass, damping and stiffness matrix

elements are calculated using the equation for the blade pitch in Reference 1. All the terms are

multiplied by the torsional mode shape, PH(r), which is a function of blade radius, except the blade pitch

terms which are multiplied by the square of the

mode shape.

USAGE:

CALL BLELPD

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

BLIN4

PURPOSE:

To provide a bivariant table lookup with linear interpolation for the airfoil data.

METHOD:

The Mach number entries are searched to find K such that

$$M_{K-1} < M < M_K$$

The angles of attack in the M_{K-1} and M_{K} tables are searched to find I and J such that

$$A_{K-1,I-1} < A < A_{K-1,I}$$

and

$$A_{K,J-1} < A < A_{K,J}$$

Then the coefficient at M_{K-1} and A is given by

$$c_{K-1} = (A - A_{K-1,I-1})*(c_{K-1,I} - c_{C-1,I-1})/$$

$$(A_{K-1,I} - A_{K-1,I-1}) + c_{K-1,I-1}$$

and the coefficient at $\mathbf{M}_{\mathbf{K}}$ and \mathbf{A} is given by

$$c_{K} = (A - A_{K,J-1})*(c_{K,J} - c_{K,J-1})/(A_{K,J} - A_{K,J-1}) + c_{K,J-1}$$

Finally, the coefficient at M and A is obtained from

$$C = (M - M_{K-1})*(C_K - C_{K-1})/(M_K - M_{K-1}) + C_{K-1}$$

$$\frac{DC}{DM} = \frac{C_K - C_{K-1}}{M_K - M_{K-1}}$$

USAGE:

CALL BLIN4 (T, M, K, X, Y, Z, D, L)

- T = A two-dimensional array containing the coefficient, angle of attack pairs. The first point in each column represents the number of pairs, the second point in each column represents the Mach number, and the remaining points in the column are the pairs for that Mach number.
- M,K = The dimensions of T
 M is the maximum number of Mach numbers in the table.
 K is the maximum column length.

X = Angle of attack.

Y = Mach number.

Z = Returned coefficient.

D = Derivative with respect to M.

L = Error switch.

1 No error

2 Mach number not spanned

3 Angle of attack not spanned

SUBROUTINES CALLED:

None

ERROR RETURNS:

See above

RESTRICTIONS:

- 1. Number of Mach numbers specified must be equal or greater than 2 and cannot be greater than 12.
- 2. Number of coefficient/angle of attack pairs must be equal or greater than 5 and cannot be greater than 35.

CMPRSS

PURPOSE:

To compress a square matrix.

METHOD:

The returned matrix of dimension L \times L is produced by taking the first L rows and columns of the input matrix

of dimension $N \times N$.

USAGE:

CALL CMPRSS (A, N, B, L)

A = Input matrix.

N = Dimensions of A.

B = Output matrix, which may have the same location

as A.

L = Dimensions of B.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

If L is equal or greater than N, no matrix compression

is done.

CMPUTE

PURPOSE:

To control calculations of the generalized forces and of the forced response for the linear bifilar

analysis.

METHOD:

First, the generalized forces are calculated in GENFOR. Then, the forced response of the linear system of equations is obtained in FORCER. The results of the analysis are printed out in a call to OUTPUT.

USAGE:

CALL CMPUTE

SUBROUTINES

CALLED:

GENFOR, FORCER, OUTPUT

ERROR RETURNS:

None

RESTRICTIONS:

COMBIN

PURPOSE:

To combine the non-linear bifilar mass matrix and the force vector developed for the non-linear bifilar analysis with the corresponding matrix and vector from the linear bifilar analysis.

METHOD:

The mass matrix and force vector calculated in BIFEXP are added to the results of the linear analysis from SYSCTL. The fixed system d.o.f. are affected. The combined mass matrix and force vector include all the degrees-of-freedom (up to the maximum of 72).

If forces are input to one or two additional aircraft stations (as specified in locations 1767 and 1940 through 2179), their corresponding contributions to the final force vector are included by pre-multiplying the input forces by the appropriate aircraft station mode shapes (see locations 550-749).

The final combined mass matrix and force vector are stored in labelled COMMON/NLDAT2.

USAGE:

CALL COMBIN (NBML, NRHS, NF, NREV)

NRHS = Total number of d.o.f. not including nonlinear bifilars (maximum is 60).

NF = Number of fixed system modes (maximum is 16).

NREV = Revolution number - loc 1762 divided by 360.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

- 1. Total number of degrees-of-freedom is 72 (60 from linear analysis and 12 for the maximum number of non-linear bifilars).
- 2. Harmonic force inputs are possible for only 2 aircraft stations.

CONVER

PURPOSE:

To test on the convergence of the time history solution for two successive revolutions.

METHOD:

This routine checks the difference in the displacements of the first two non-linear bifilar pendulums obtained for two successive revolutions. If both differences are within .002 radian (corresponding to .1146 degree), then the convergence criterion is satisfied; IER (see below) is set to 1 and the program returns to NLBIF to calculate one more revolution after which the harmonic analysis is performed and printed out. If one of the differences is greater than .002 radian, the time history analysis proceeds to the next revolution.

The revolution number, the two bifilar displacement differences and the rotor hub x, y, θ_Z , \dot{x} , \dot{y} motions are all listed out for each revolution.

USAGE:

CALL CONVER (I, IER)

I = Rotor revolution number - location 1762 divided by 360.

IER = Convergence criterion - it is met if equal to 1.

SUBROUTINES CALLED.

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

DISCON

PURPOSE:

To adjust a blade stepwise function so that it is

defined only over the blade.

METHOD:

The input segments are extended or truncated so that the first segment starts at the offset and the final segment finishes at the blade radius. Function values are unaltered but may be discarded if the segment they refer to is completely outside the blade.

USAGE:

CALL DISCON (KSTAR, DELTAR, NSTAR, E, R, RBAR, KBAR,

N1BAR)

KSTAR = Array of input stepwise function values.

DELTAR = Array of segment lengths over which KSTAR

is defined.

NSTAR = Number of entries in KSTAR and DELTAR.

E = Blade offset.

R = Blade radius.

RBAR = Array of adjusted segment lengths.

KBAR = Array of stepwise function values defined

over RBAR.

N1BAR = Number of entries in RBAR and KBAR.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

DISINT

PURPOSE:

To perform the integration of the product of a step function and a radial function over the blade length.

METHOD:

The stepwise function is first adjusted by DISCON so that it is defined over a segment distribution which starts at the offset and finishes at the blade radius. The integration of the radial function is then performed separately over each of these segments and multiplied by the value of the stepwise function for that segment. The final answer is the sum of these results.

i.e.
$$\int_{E}^{R_{N}} f(r)S(r)dr = S_{1} \int_{E}^{R_{1}} f(r)dr + S_{2} \int_{R_{1}}^{R_{2}} f(r)dr + ...$$

$$S_{k} \int_{R_{K-1}}^{R_{k}} f(r)dr + ... + S_{N} \int_{R_{N-1}}^{R_{N}} f(r)dr$$

where

 S_K = the value of the stepwise function over the K^{th} segment.

f(r) = the radial function

USAGE:

CALL DISINT (COMP, R, N, FPPP, RPPP, NM2, E, CR, SUM)

COMP = Array of radial function values.

R = Array of radii at which COMP is defined

N = Number of points in COMP and R.

FPPP = Array of stepwise function values.

RPPP = Array of segment lengths over which FPPP is defined.

USAGE:

NM2 = Number of entries in FPPP and RPPP.

E = Blade offset.

CR = Blade radius.

SUM = Integral of the product of the two functions.

SUBROUTINES

CALLED:

DISCON, INTEG

ERROR RETURNS:

None

RESTRICTIONS:

DMATEX

PURPOSE:

To expand the dynamic matrices to include the blade

elastic torsional mode.

METHOD:

The original dynamic mass (DMM), damping (DMD) and stiffness (DMS) matrices are increased by 3 rows and

columns and redefined as DMMN, DMDN and DMSN respectively

to accomodate one collective and two cyclic modes associated with the blade elastic torsional mode.

USAGE:

CALL DMATEX

SUBROUTINES

None

CALLED:

ERROR RETURNS:

None

RESTRICTIONS:

The matrices are limited to 30×30 .

DMDMAT

PURPOSE:

To calculate the dynamic damping matrix.

METHOD:

The matrix is calculated from the expressions given in Reference 1, using the dynamic integrals calculated

in DYNINT.

USAGE:

CALL DMDMAT

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

DMMMAT

PURPOSE:

To calculate the dynamic mass matrix.

METHOD:

The matrix is calculated from the expressions given in Reference 1, using the dynamic integrals calculated

in DYNINT.

USAGE:

CALL DMMMAT

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

DMSMAT

PURPOSE:

To calculate the dynamic stiffness matrix.

METHOD:

The matrix is calculated from the expressions given in Reference 1, using the dynamic integrals calculated in DYNINT.

USAGE:

CALL DMSMAT

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

DYNINT

PURPOSE:

To set the initial values of the dynamic integrals to zero and to control the calculation of the integrals needed to construct the dynamic mass, damping, and stiffness matrices.

METHOD:

The dynamic integrals are obtained from the integration of the product of a radial function and a stepwise function over the blade length. All integrals have the blade mass or the edgewise, flatwise, and torsional mass moments of inertia as their stepwise function.

If the radial function is independent of the blade bending modes, then the integrals are calculated in DYNIN1. Integrals with singly and doubly subscripted

radial functions are handled in DYNIN2.

USAGE:

CALL DYNINT

SUBROUTINES

CALLED:

DYNIN1, DYNIN2

ERROR RETURNS:

None

RESTRICTIONS:

DYNIN1

PURPOSE:

To calculate the dynamic integrals whose setpwise function is either the blade mass or the edgewise, flatwise, or torsional mass moment of inertia and whose radial functions contain no blade bending mode

dependent quantities.

METHOD:

These integrals are formed in DISINT from the product of a radial function and a stepwise function integrated over the blade length. The radial function

may itself be a product of radial functions.

The integrals which are a function of blade mass are referred to as unsubscripted BMK. The integrals dependent on the blade mass moments of inertia are

referred to as unsubscripted BIK.

USAGE:

CALL DYNIN1

SUBROUTINES

CALLED:

DISINT

ERROR RETURNS:

None

RESTRICTIONS:

DYNIN2

PURPOSE:

To calculate the dynamic integrals whose stepwise function is either the blade mass or the edgewise, flatwise, or torsional mass moment of inertia and whose radial function contains one or two blade bending

mode dependent quantities.

METHOD:

These integrals are formed in DISINT from the product of a radial function and a stepwise function. The integrals which are a function of blade mass are referred to as BMJ and BMI for singly and doubly subscripted values respectively. The integrals dependent on the blade mass moments of inertia are referred to as BIJ and BII for singly and doubly subscripted values

respectively.

USAGE:

CALL DYNIN2

SUBROUTINES

CALLED:

DISINT

ERROR RETURNS:

None

RESTRICTIONS:

DYNLST

PURPOSE:

To print out the dynamic integrals.

METHOD:

If the print option is set to 3 or 4, the integrals are printed. Otherwise, control is returned to DYNMAT.

Only those integrals calculated are printed.

USAGE:

CALL DYNLST

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

DYNMAT

PURPOSE:

To control the calculation of the dynamic mass, damping

and stiffness matrices.

METHOD:

The dynamic integrals needed to calculate the elements of the matrices are evaluated in DYNINT, stored in labelled COMMON/DYNOUT, and printed out by DYNLST. DYNMAT then makes calls to DMMMAT, DMDMAT and DMSMAT to calculate the mass, damping and stiffness matrices respectively. Then, it expands the matrices in DMATEX to include the blade torsional elastic mode terms, which are calculated in BLELPD.

In addition, several blade parameters are calculated and printed out according to the degrees-of-freedom

being used.

USAGE:

CALL DYNMAT

SUBROUTINES CALLED:

DYNINT, DYNLST, DMMMAT, DMDMAT, DMSMAT, DMATEX, BLELPD

ERROR RETURNS:

None

RESTRICTIONS:

EIGER

PURPOSE:

To compress and link the rotor matrices to the bifilar

analysis.

METHOD:

The degrees-of-freedom not utilized are eliminated from

the rotor dynamic and aerodynamic matrices. The

dynamic and aerodynamic damping and stiffness matrices are added together. Then, the 30 x 30 matrices are compressed to K X K in CMPRSS. The final compressed matrices (3) are stored in labelled COMMON/INEIG for coupling with the bifilar analysis. The matrices can be printed out and/or punched out in cards if desired.

USAGE:

CALL EIGER

SUBROUTINES

CALLED:

CMPRSS

ERROR RETURNS:

None

RESTRICTIONS:

ELI

PURPOSE:

To calculate the forces and moments needed to create the elastic matrix associated with the inboard half of a segment.

METHOD:

The forces and moments are calculated using the expressions derived in Reference 2.

USAGE:

CALL ELI(I)

I = Blade segment number.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

ELO

PURPOSE:

To calculate the forces and moments needed to create the elastic matrix associated with the outboard half

of a segment.

METHOD:

The forces and moments are calculated using the ex-

pressions derived in Reference 2.

USAGE:

CALL ELO(I)

I = Blade segment number.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

EXTEND

PURPOSE:

To find the values of a function at a set of points, given the function values at a different set of points.

METHOD:

The value of the function at a new point is obtained by linear interpolation between the two closest old points.

USAGE:

CALL EXTEND (F, R, M, RSTAR, N)

F = On input, the old function values. On output, the new function values.

R = The set of points at which F is defined on input.

M = Number of points in F and R.

RSTAR = The set of points at which F is defined on output.

N = The number of points in RSTAR and F on output.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

N must be less than or equal to 400.

F159X

PURPOSE:

To calculate the blade elastic torsional frequency.

METHOD:

The torsional frequency is found from repeated calls to ROOTX which calculates the torsional mode shape. The frequency trials start at zero frequency and proceed in steps of 10 rad/sec up to a maximum of 1990 rad/sec. After each trial. a check is made on the sign of the root mode shape. If a change in sign is found, then the frequency has been found. Three more iterations are performed to zero-in the frequency value (difference in 2 successive values

of the root mode shape is within .0001).

USAGE:

CALL E159X

SUBROUTINES CALLED:

R00TX

ERROR RETURNS:

If after 200 trials no sign change in the root mode shape has been found, then an error message is printed out as follows:

'OUT OF RANGE'

followed by the last frequency trial value and the root mode shape value.

RESTRICTIONS:

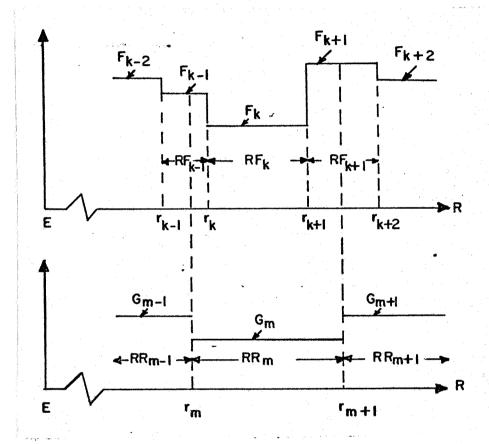
- 1. Frequency upper limit is 1990 rad/sec.
- Only the first elastic torsional frequency is 2. found.
- 3. Three trials allowed to zero-in the final frequency value.

FILL

PURPOSE:

To find the value/length of a second moment of area function over each of the blade segments, given the function/length values over some other segment distribution.

METHOD:



The redistributed function \boldsymbol{G}_{m} is defined below for new segment $\mathsf{RR}_{m} \colon$

$$\frac{\mathsf{RR}_{m}}{\mathsf{G}_{m}} \ = \ \frac{\mathsf{r}_{k} - \mathsf{r}_{m}}{\mathsf{F}_{k-1}} \ + \ \frac{\mathsf{r}_{k+1} - \mathsf{r}_{k}}{\mathsf{F}_{k}} \ + \ \frac{\mathsf{r}_{m+1} - \mathsf{r}_{k+1}}{\mathsf{F}_{k+1}}$$

Where:

F_k = Old function values

RF_k = 01d blade segments

 r_k = Radial positions of function from hinge (E)

 G_{m} = New function values RR_{m} = New blade segments

USAGE:

CALL FILL (RR, NSEG, F, RF, NF, E)

RR = An array containing the blade segment lengths.

NSEG = The number of segments in 'RR.

F = On input, the function values over RF.
On output, the function values over RR.

RF = An array containing the segment lengths over which F is defined on input.

NF = The number of segments in RF.

E = The offset of the blade from the center of rotation.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

NSEG must be less than or equal to 25.

FIXABS

PURPOSE:

To calculate the fixed system absorber matrices

in the bifilar analysis.

METHOD:

This routine initializes the matrices to zero. Then, it defines needed parameters from the input vector, V, and proceeds to evaluate the mass damping and stiffness elements according to the equations from Reference

3.

Printout of final matrices is controlled by location

10.

USAGE:

CALL FIXABS

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

Number of fixed system absorber cannot be greater

than 5.

FIXSYS

PURPOSE:

To calculate the fixed system modes matrices

in the bifilar analysis.

METHOD:

The fixed system modal mass, damping and stiffness elements are calculated according to the expressions

in Reference 3.

A printout of the matrices can be obtained if location

10 is set to 1.

USAGE:

CALL FIXSYS

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

FOLL

PURPOSE:

To convert a blade function from value/length to an

equivalent radial function.

METHOD:

The input function is first converted into a cumulative function with values at the end points of the input segment distribution. The value then assigned to a radial point is derived by finding the cumulative values at the end points of the segment that the radial point represents and subtracting them.

USAGE:

CALL FOLL (RAD, F, NF, RB, NB, E, RR)

RAD = Segment lengths of input distribution.

F = Input stepwise function.

NF = Number of elements in RAD and F.

RB = The radial points at which values are required.

NB = The number of elements in RB.

E = The blade offset.

RR = The segment lengths to be associated with

the radial points in RB.

SUBROUTINES CALLED:

EXTEND

ERROR RETURNS:

None

RESTRICTIONS:

FORCER

PURPOSE:

To solve for the forced response of the linear bifilar

analysis.

METHOD:

At first, this routine combines the generalized force

cosine and sine vectors and prints out the final

vector, FRC, of dimension 2*NF. Then, it inverts the hub impedance matrix, T, by a call to LINV2F and forms the fixed system generalized coordinates vector, XQ, of dimension 2*NF. The generalized coordinates vector

of all the system degrees-of-freedom, GAMMA, of

dimension 90, is calculated from a multiplication of the transfer matrix, TRANSF, and the XQ vector. The final vector GAMMA is used to calculate and print out the forced response amplitudes and phase angles of the

fixed system absorbers and bifilar pendulums.

The GAMMA vector is printed out if location 1497 is set

to 1.0.

USAGE:

CALL FORCER

SUBROUTINES CALLED:

LINV2F

(This is an "IMSL" package routine which must be

supplied by the Army).

ERROR RETURNS:

None

RESTRICTIONS:

Refer to subroutine HUBIMP.

FREQUN

PURPOSE:

To calculate the blade natural frequencies.

METHOD:

The natural frequencies are the eigenvalues of the matrix formed by applying suitable boundary conditions to the matrix relating forces, etc., at the blade tip to the blade root.

The eigenvalues are found by assuming an initial frequency and then increasing it by a predetermined increment until a change in sign of the determinant occurrs. Newton's method is then used to improve the answer until $|F_{i+1} - F_i| < .001$.

The search for further natural frequencies continues until either the requested number has been found or the upper frequency limit is reached.

The starting values for the frequency trials is .15 Ω where Ω is the rotor speed in rad/sec.

The frequency scan interval is .10 Ω .

USAGE:

CALL FREQUN

SUBROUTINES CALLED:

PRODM, MIND

ERROR RETURNS:

'EXCEEDED UPPER FREQUENCY LIMIT'

The program will search for the number of frequencies requested up to a frequency of 75 cycles/rev.

The program continues using the number of natural frequencies that have been found.

'DID NOT CONVERGE AFTER SIGN CHANGE - 100 TRIALS'

Having located a change in sign of the determinant, the program was unable to improve the eigenvalue sufficiently to satisfy the convergency test in 100 trials. The program continues using the last estimate.

3. 'FAILED TO LOCATE SIGN CHANGE AFTER 500 TRIALS'

An eigenvalue was not detected in the frequency range 0.0 to 75 cycles/rev. The program continues with a frequency of 75 cycles/rev.

4. 'AN EVEN NUMBER OF FREQUENCIES HAVE BEEN MISSED'

Two frequencies differ by less than .0015 Ω - .00001 (Ω is the rotor speed). The program treats them as one frequency and continues.

RESTRICTIONS:

- 1. Frequencies cannot be calculated at zero rotor speed. It is suggested that rotor speed be lowered gradually to about 50 rad/sec. Computer time increases tremendously as rotor speed decreases since the scan interval is set at $.10\Omega$.
- See notes on "ERROR RETURNS".

FULL

PURPOSE:

To find the values of an area function over each of the blade segments, given the function/length values over some other segment distribution.

METHOD:

Same method as discussed for subroutine "FILL".

USAGE:

CALL FULL (RR, NSEG, F, RF, NF, E)

RR = An array containing the blade segment lengths.

NSEG = The number of segments in RR.

F = On input, the function values/length over L. On output, the function values/length over RR.

RF = An array containing the segment lengths over
 which F is defined on input.

NF = The number of segments in RF.

E = The offset of the blade from the center of rotation.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

NSEG must be less than or equal to 25.

GENFOR

PURPOSE:

To calculate the generalized forces for the linear

bifilar analysis.

METHOD:

The generalized force vectors for the cosine (FQC) and sine component (FQS) are calculated from the force input vectors (locations 110-289) provided for the main and tail rotor hubs and 2 additional aircraft points and their appropriate mode shapes

(locations 450-749 and 850-949).

The force vectors of dimension NF (location 9) are

passed through labelled COMMON/XFRDAT.

USAGE:

CALL GENFOR

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

GMPRDD

PURPOSE:

To multiply two general matrices to form a resultant

general matrix.

METHOD:

The M X L matrix B is premultiplied by the N X M

matrix A and the result is stored in the N X L

matrix R.

RESULT:

Χ В NXL NXM MXL

USAGE:

CALL GMPRDD (A, B, R, N, M, L)

A = First input matrix.

Second input matrix.

Output matrix.

Number of rows in A.

M = Number of columns in A and rows in B.

L = Number of columns in B.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

HARMON

PURPOSE:

To perform harmonic analysis of the time history

solution.

METHOD:

The solution acceleration vector calculated in INTEQ and passed through labelled COMMON/NLDAT2 is harmonically analyzed once the convergence criterion is met

in routine CONVER.

The harmonics are stored in labelled COMMON/HARM.

USAGE:

CALL HARMON (IC, N1)

IC = Rotor revolution number - location 1762 divided

by 360.

N1 = Total number of degrees-of-freedom (maximum

is 72).

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

The number of harmonics output is limited to 10.

HUBIMP

PURPOSE:

To develop the transfer and hub impedance matrices

for the linear bifilar analysis.

METHOD:

At first, the final mass (XMFC) and stiffness (XKFC) are combined to form matrix A (= XKFC -WF²*XMFC), where WF is the forcing frequency. Then, the damping matrix (XCFC) is used to form matrix B (= WF*XCFC). If no fixed system absorbers and no linear bifilars are present in the system, the routine calculates the hub impedance matrix, E, from matrices A and B and then returns to MAINSV; otherwise, it proceeds to calculate the transfer matrix, TRANSF, after a call to LINV2F, and subsequently the hub impedance matrix E. (Additional information can be obtained in Ref. 3).

The transfer and hub impedance matrices are passed through labelled COMMON/XFRDAT.

Throughout the matrix calculations performed, the resulting matrices can be printed out using the control switches in locations 10 and 15.

USAGE:

CALL HUBIMP

SUBROUTINES CALLED:

LINV2F

(This is an "IMSL" package routine which must be supplied by the government)

ERROR RETURNS:

None

RESTRICTIONS:

Number of degrees-of-freedom of the final system matrices (XMFC, XKFC, XCFC) is limited to 60 as follows:

a.	Fixed system modes	16
b.	Fixed system absorbers	5
С.	Linear bifilars (5X3)	15
d.	Rotor Modes	24
		$\overline{60}$ = Total

- 2) The transfer matrix (TRANSF) maximum dimensions are (90X32) where 90 represents 2 times the maximum d.o.f. of the fixed system absorber plus the bifilar and rotor modes and 32 is 2 times the maximum number of fixed system d.o.f.
- 3) The hub impedance matrix (E) has maximum dimensions of (32X32) obtained from 2 times the maximum fixed system d.o.f.

INCOND

PURPOSE:

To initialize quantities to zero in the bifilar analysis.

METHOD:

The system mass, damping and stiffness matrices (XMFC, XCFC, XKFC respectively) of dimensions 60X60 are set to zero. In addition, the matrices (10X75) used to store the harmonic results (CHARM and SHARM) are zeroed out. The input location 1498 controls the initialization of the bifilar pendulums, the rotor hub and the state variables displacements and

velocities.

USAGE:

CALL INCOND

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

INPUTV

PURPOSE:

To provide a description of the input locations to the bifilar analysis and to read the input data.

METHOD:

Locations 1 through 2200 are listed and discussed - all lines of code are of course commented out. Then, a call is made to LOADIT to read the input data.

USAGE:

CALL INPUTV

SUBROUTINES

CALLED:

LOADIT

ERROR RETURNS:

None

RESTRICTIONS:

INTEG

PURPOSE:

To convert a function defined at unequally spaced argument points, to an equal function defined at a set number of equally spaced points in a given interval and integrate it using the trapezoidal rule.

METHOD:

The length of the interval is divided by the number of divisions required to obtain the argument spacing. Function values at these subdivision points are obtained by linearly interpolating between the two nearest existing function values. The redistributed function is then passed to OTFG for integration.

USAGE:

CALL INTEG (F, R, NSEG, RBAR1, RBAR2, N, XI)

F = Array of function values.

R = Array of argument values at which F is

defined.

NSEG = Number of blade segments

RBAR1 = Lower limit of the interval of integration.

RBAR2 = Upper limit of the interval of integration.

N = Number of subdivisions to be used.

XI = Integral.

SUBROUTINES CALLED:

QTFG

ERROR RETURNS:

None

RESTRICTIONS:

N must be less than or equal to 100.

INTEQ

PURPOSE:

To calculate the time history solution of the nonlinear equations of motion.

METHOD:

The combined mass matrix (XMT) and force vector (FT) of dimensions NT developed in COMBIN are used to obtain the time history response of the non-linear system. The procedure is discussed below.

Given
$$[XMT] \{\dot{q}\} = \{FT\},$$

first, the matrix and vectors are partitioned as follows:

$$\begin{bmatrix} \mathsf{XMT}_{\mathsf{A}} & \mathsf{XMT}_{\mathsf{B}} \\ \mathsf{----} & \mathsf{---} \\ \mathsf{XMT}_{\mathsf{C}} & \mathsf{I} \end{bmatrix} \begin{bmatrix} \mathsf{q}_1 \\ \mathsf{q}_2 \\ \mathsf{q}_2 \end{bmatrix} = \begin{bmatrix} \mathsf{FT}_1 \\ \mathsf{---} \\ \mathsf{FT}_2 \end{bmatrix}$$

where the square matrix, $[XMT_A]$, the acceleration vector part, $\{q_1\}$, and the force vector part, $\{FT_1\}$, have dimensions (NT-ND) and include only the degreesof-freedom associated with the fixed system and rotor modes, while the unity matrix, [I], the acceleration vector part, $\{\dot{q}_2\}$, and the force vector part, {FT₂}, have dimensions ND and include the rest of the d.o.f. of the system.

Next, the accelerations are solved for as shown below:

1)
$$\left[XMT_{A}\right] \left\{\dot{q}_{1}\right\} + \left[XMT_{B}\right] \left\{\dot{q}_{2}\right\} = \left\{FT_{1}\right\}$$

1)
$$\begin{bmatrix} XMT_A \end{bmatrix} \begin{Bmatrix} \dot{q}_1 \end{Bmatrix} + \begin{bmatrix} XMT_B \end{bmatrix} \begin{Bmatrix} \dot{q}_2 \end{Bmatrix} = \begin{Bmatrix} FT_1 \end{Bmatrix}$$
2)
$$\begin{bmatrix} XMT_C \end{bmatrix} \begin{Bmatrix} \dot{q}_1 \end{Bmatrix} + \begin{bmatrix} I \end{bmatrix} \begin{Bmatrix} \dot{q}_2 \end{Bmatrix} = \begin{Bmatrix} FT_2 \end{Bmatrix}$$

Solve for $\{q_2\}$ from equation 2) above.

3)
$$\left\{ \overrightarrow{q}_{2} \right\} = \left\{ FT_{2} \right\} - \left[XMT_{C} \right] \left\{ \overrightarrow{q}_{1} \right\}$$

Then, the solution vector q_1 is given by substituting 3) into 1) above.

4)
$$\left(\begin{bmatrix} XMT_A \end{bmatrix} - \begin{bmatrix} XMT_B \end{bmatrix} \begin{bmatrix} XMT_C \end{bmatrix} \right) \left\{ \vec{q_1} \right\} = \left\{ FT_1 \right\} - \left[XMT_B \right] \left\{ FT_2 \right\}$$

which can be written as,

5)
$$\left[XXT \right] \left\{ \begin{array}{c} \ddots \\ q_1 \end{array} \right\} = \left\{ XT \right\}$$

The routine forms the matrix [XXT] and the vector $\{XT\}$ (note that the maximum dimensions of (NT-ND) are 40).

The acceleration vector, $\{\dot{q}_1\}$, is solved for in the IMSL routine LEQT2F. Subsequently, the acceleration vector, $\{\dot{q}_2\}$, is evaluated from expression 3) above.

The analysis proceeds next to integrate the combined acceleration vector, $\{\dot{q}^i\}$, to obtain the velocity and displacement vectors using the expressions below:

6)
$$\left\{\dot{q}\right\}_{t+\Delta t} = \left\{\dot{q}\right\}_{t} + \Delta t \left\{\dot{q}\right\}_{t}$$

7)
$$\{q\}_{t+\Delta t} = \{q\}_t + \Delta t \{\dot{q}\}_t$$

where the time increment, At, is defined from

8)
$$\Delta t = \frac{\Delta \psi \text{ (deg-loc 1761)}}{\Omega \text{ (rpm-loc 7) *6}}$$
, seconds

The resulting velocity vector is loaded into the input vector, V, in locations 1740-1759 for the non-linear bifilars and in locations 1860-1939 for the remaining d.o.f., while the displacement vector is loaded similarly into locations 1720-1739 and locations 1780-1859. The rotor hub velocities and displacements are also calculated by pre-multiplying the resulting vectors by the transfer matrix (input in locations 450-549). The resulting velocity and displacement vectors are printed out at every azimuth position up to 30 degrees. The final step in INTEQ is to increment the azimuthal angle and return to NLBIF.

The final results are passed through labelled COMMON/INDAT for the input vector V and through labelled COMMON/NLDAT2 for the solution acceleration vector $\left\{\dot{q}^{*}\right\}$.

USAGE:

CALL INTEG (NT, ND)

NT = Total number of d.o.f. (72 maximum).

ND = NT minus number of d.o.f. of fixed system (16 maximum) and rotor (24 maximum); maximum value of ND is 32.

SUBROUTINES CALLED:

LEQT2F

(This is an "IMSL" package routine which must be supplied by the Army).

ERROR RETURNS:

None

RESTRICTIONS:

The maximum order of the solution vector (as obtained

from LEQT2F) is 40.

LINBIF

PURPOSE:

To calculate the linear inplane bifilar matrices

METHOD:

This routine defines needed parameters from the input vector, V, to start. Then, it initializes the matrices to zero and proceeds with the calculations of the mass, damping and stiffness elements according to the expressions published in Ref. 3. The matrices are of order 9X9 and consist of the following degrees-of-freedom:

- 1. Fixed system longitudinal
- Fixed system lateral
- Fixed system vertical
- Fixed system roll
- 5. Fixed system pitch
- Fixed system yaw
- 7. Bifilar symmetric mode
- 8. Bifilar cyclic (sine) mode
- 9. Bifilar cyclic (cosine) mode

A printout of the bifilar matrices can be obtained by setting location 1495 to 1.0.

USAGE:

CALL LINBIF

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

- 1. Number of bifilars in each kind is limited to 10.
- 2. Number of different bifilar kinds (inplane and vertical) cannot be greater than 5.

LOADIT

PURPOSE:

To read a data card, and then after checking the characters, to store the data in the specified locations.

METHOD:

Each card in the input stream is read and printed out before any interpretation is attempted. Each character on the card is then checked for validity. Column one must be -, +, 0 or blank; column two must be 1 through 5; columns three through six must be +, 0 - 9, or blank; and columns seven through sixty-six can be -, +, 1, 0 - 9, E or blank.

A minus in column one indicates end of input data for that case.

Column two contains the number of values to be read in.

Columns three through six contain the input location at which to start storing the values. If the address is zero or blank, the next location is used.

Columns seven through sixty-six contain the values to be stored. A format of 5E12.4 is assumed.

USAGE:

CALL LOADIT(X, NFILE)

X = An array into which the data is placed.

In the rotor analysis, X = INPUT (which is equivalent to blank COMMON).

In the bifilar analysis, X=V (which is equivalent to labelled COMMON/INDAT.

NFILE = 5. The read unit file for both rotor and bifilar analyses.

SUBROUTINES CALLED:

None

ERROR RETURNS:

Any error results in the card that caused the error being ignored.

RESTRICTIONS:

- *1) LOADIT is one of four routines which are computer dependent. Coding for both IBM and CDC computer systems is retained with appropriate lines commented out.
- 2) The maximum number of input locations is 8100 for the rotor analysis and 2200 for the bifilar analysis.

LVBIF

PURPOSE:

To calculate the linear vertical bifilar matrices

METHOD:

This routine defines needed parameters from the input vector, V, to start. Then, it initializes the matrices to zero and proceeds with the calculations of the mass, damping and stiffness elements according to the expressions published in Ref. 3. The matrices are of order 9X9 and consist of the following degrees-of-freedom:

- 1. Fixed system longitudinal
- 2. Fixed system lateral
- Fixed system vertical
- Fixed system roll
- Fixed system pitch
- 6. Fixed system yaw
- 7. Bifilar symmetric mode
- 8. Bifilar cyclic (sine) mode
- 9. Bifilar cyclic (cosine) mode

A printout of the bifilar matrices can be obtained by setting location 1496 to 1.0.

USAGE:

CALL LVBIF

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

- 1. Number of bifilars in each kind is limited to 10.
- 2. Number of different bifilar kinds (inplane and vertical) cannot be greater than 5.

MAINSV

PURPOSE:

To control the principal logic flow of the bifilar analysis portion of the rotor/bifilar coupled program.

METHOD:

MAINSV first calls INPUTV which calls LOADIT to read the input data for the case at hand. Then, the bifilar matrices and other quantities are set to zero in INCOND. The contributions of the fixed system modes, the rotor (if used), the fixed system absorbers, and the linear inplane and vertical bifilar pendulums to the final system mass, damping and stiffness matrices are added in SYSCTL. The program then proceeds to calculate the hub impedance and transfer matrices in HUBIMP, and the generalized forces and the forced response in CMPUTE for the linear analysis case.

If non-linear inplane bifilars are to be analyzed, the program bypasses HUBIMP and CMPUTE and instead it activates NLBIF to calculate the time-history response of the system.

USAGE:

CALL MAINSV (1927SW, NCASE)

I927SW = \neq 0 Include rotor contributions.

O Do not include rotor contributions.

NCASE = 1 Input vector, V(2200), is initialized to zero and the bifilar analysis title (second one) is read in.

Input vector is not set to zero and the second title card is not read.

SUBROUTINES CALLED:

INPUTY, INCOND, SYSCTL, HUBIMP, CMPUTE, NLBIF

ERROR RETURNS:

None

RESTRICTIONS:

MATEI

PURPOSE:

To calculate the elastic matrix associated with the

inboard half of a rotor blade segment.

METHOD:

The 13 X 13 matrix is calculated using the expressions

derived in Reference 2 and the forces and moments

calculated in ELI.

USAGE:

CALL MATEI(I)

I = Blade segment number.

SUBROUTINES

CALLED:

MIND, GMPRDD

ERROR RETURNS:

None

RESTRICTIONS:

MATEO

PURPOSE:

To calculate the elastic matrix associated with the

outboard half of a rotor blade segment.

METHOD:

The $13\ X\ 13$ matrix is calculated using the expressions

derived in Reference 2 and the forces and moments

calculated in ELO.

USAGE:

CALL MATEO(I)

I = Blade segment number.

SUBROUTINES

CALLED:

MIND, GMPRDD

ERROR RETURNS:

None

RESTRICTIONS:

MATF

PURPOSE:

To calculate the mass transfer matrix which relates

the blade forces across a concentrated mass.

METHOD:

The 13 X 13 matrix is calculated using the expressions

derived in Reference 2.

USAGE:

CALL MATF(I,W)

I = Blade segment number.

W = Rotational speed.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

MATR

PURPOSE:

To calculate the transformation matrix associated

with a discontinuity in blade twist.

METHOD:

The 13 X 13 matrix is calculated using the expression derived in Reference 2 and represents the change in

twist from segment I to segment I-1.

USAGE:

CALL MATR(I)

I = Blade segment number.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

MIND

PURPOSE:

To invert a matrix and calculate its determinant.

METHOD:

The routine is an adaption of the routine MINV from the IBM Scientific Subroutine Package, which uses the standard Gauss-Jordan reduction to obtain the inverse. The value of the determinant is obtained simultaneously as the product of the pivot.

To avoid possible overflow conditions, the value of the determinant is expressed in the form D X $10^{\,\mathrm{I}}$, where D is between 1.0 and 10.0, by repeated calls to OVUN.

USAGE:

CALL MIND (A, N, D, L, M, IE)

A = The matrix to be inverted; it is destroyed during the computation.

N = The dimensions of A.

D = Determinant value.

L = Work vector of length N.

M = Work vector of length N.

IE = Power of 10 to be associated with D.

SUBROUTINES CALLED:

OVUN

ERROR RETURNS:

A determinant of zero indicates a singular matrix.

RESTRICTIONS:

MISC

PURPOSE:

To perform initial calculations on the input data for the blade frequency and mode shape calculations.

METHOD:

The input segment lengths are used to construct an array of radii to the segment centers, and the local twist distribution is used to construct the twist discontinuities.

USAGE:

CALL MISC

SUBROUTINES CALLED:

None

ERROR RETURNS:

The sum of the segment lengths is checked against the blade radius; a difference of more than 10% produces the following warning:

'INCOMPATABILITY BETWEEN RADIUS AND SUM OF SEGMENTS'.

The program continues with the input values.

MODES

PURPOSE:

To control the calculations of the rotor blade fullycoupled frequencies and mode shapes.

METHOD:

The blade is assumed to consist of a number of spanwise segments with the inertial loading on each segment concentrated at the center. Each segment is then divided into two parts: one inboard and one outboard of the concentrated mass. The half segments are treated as weightless, with the concentrated mass being located at the junction between them. The elastic properties are assumed to be constant within the inboard and outboard halves of the segment. The builtin blade twist is incorporated in the model by permitting angle changes at the junction between segments.

Relationships between blade forces, moments, and elastic deformations at the tip and at the root of the blade can be obtained by considering the changes in these variables over the blade segments. Elastic matrices are used to give the change across the inboard and outboard sections of the segments. Transformation matrices account for the change due to an abrupt change in twist at the segment junctions, and mass transfer matrices give the change from a position just outboard to just inboard of a concentrated mass at the center of a segment. The product of these matrices for all segments will relate the variables at the tip to those at the root.

By applying suitable boundary conditions and iterating on frequency, the blade natural frequencies and hence the mode shapes can be derived.

USAGE:

CALL MODES

SUBROUTINES

MISC, PINT, FREQUN, MSHAPE, POUT, ORTHOG

CALLED:

ERROR RETURNS:

None

RESTRICTIONS:

MSHAPE

PURPOSE:

To calculate the blade mode shapes and their first

and second derivatives.

METHOD:

This routine first determines whether the mode shape will be predominantely flatwise, edgewise, or torsional by examining the size of the determinant of the matrix relating the tip properties to the root properties at a

frequency just less than the natural frequency.

This knowledge is used in setting up a series of simultaneous equations whose solutions yield the required mode shape on substitution into expressions

derived in Reference 2.

USAGE:

CALL MSHAPE

SUBROUTINES

CALLED:

PRODM, MIND, OVUN, SIMLIN, MATF, ELO, MATEO, MATR, ELI,

MATEI, GMPRDD

ERROR RETURNS:

None

RESTRICTIONS:

NLBIF

PURPOSE:

To control the non-linear bifilar analysis calculations.

METHOD:

The non-linear bifilar analysis is performed if the control switch in location 18 is set to 1 and the number of non-linear bifilars in location 1763 is greater than zero.

At first, the routine calculates the total number of degrees-of-freedom and proceeds with the calculations if it is equal or less than 72. Then, it calculates the time history response by calling, in sequence, the routines RHS, BIFILR, BIFEXP, COMBIN, INTEQ for each rotor revolution until either the maximum azimuth angle (input location 1762) is reached or the convergence criterion is met, as specified in CONVER. In either case, the analysis proceeds to analyze the harmonic response of the bifilar pendulums, the rotor hub and the aircraft stations in HARMON. The results are printed out in the routine OUT. The initial values of the bifilar, hub and state variables displacements and velocities are then listed to be used as starting values for the next case.

USAGE:

CALL NLBIF

SUBROUTINES CALLED:

RHS, BIFILR, BIFEXP, COMBIN, INTEQ, HARMON, CONVER, OUT

ERROR RETURNS:

If the number of degrees-of-freedom is greater than 72, then the non-linear bifilar analysis is not activated and the following message is printed out:

'TIME HISTORY SOLUTION WAS NOT PERFORMED SINCE TOTAL NUMBER OF D.O.F. = , I.E. > 72'.

RESTRICTIONS:

- 1. Number of non-linear inplane bifilars is limited to 12.
- 2. Total number of d.o.f. is 72 (60 from linear analysis plus 12 for non-linear analysis).

ORTHOG

PURPOSE:

To test the orthogonality of the blade mode shapes.

METHOD:

The orthogonality relation is shown below.

ORTH(i,j) =
$$\frac{\sum_{k} m_{k} \phi_{i,k} \phi_{j,k}}{\sqrt{\sum_{k} m_{k} (\phi_{i,k}^{2} + \phi_{j,k}^{2})}}$$

where $m_k = Mass of segment k$.

 $\phi_{i,k} = i \frac{th}{mode}$ mode shape for segment k.

 $\phi_{j,k} = j\frac{th}{mode}$ mode shape for segment k.

USAGE:

CALL ORTHOG

SUBROUTINES CALLED:

None

ERROR RETURN:

None

RESTRICTIONS:

OUT

PURPOSE:

To print out the harmonic results for the non-linear

bifilar analysis.

METHOD:

At first, this routine calculates some parameters from the input vector V. Then, it uses the harmonic

analysis results from HARMON to calculate the

amplitudes and phase angles of the harmonic response of the non-linear bifilar pendulums, the rotor head and the aircraft stations. Appropriate multiplications with the mode shapes input for the fixed system and

the aircraft stations are performed.

USAGE:

CALL OUT (NTOT, N1)

NTOT = Total number of system d.o.f.

excluding the number of non-linear bifilars.

N1 = Total number of system d.o.f.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

- 1. Maximum number of output harmonics is 10.
- 2. Maximum number of aircraft stations whose response is harmonically analyzed is 4.

OUTPUT

PURPOSE:

To calculate and print the aircraft and rotor hub

forced response.

METHOD:

This routine uses the results from FORCER (specifically

vector XQ) to calculate the forced response at specific

aircraft stations (up to 4) where mode shapes are loaded in locations 1000 through 1399 and at the rotor head using the mode shape in locations 450 through

549.

USAGE:

CALL OUTPUT

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

The response of the aircraft can be evaluated at a

maximum of 4 stations.

OVUN

PURPOSE:

To express A in the form B x 10^{I} , where

1.0<B<10.0.

METHOD:

If A is greater than 10.0, it is continually divided by 10.0 until it is less than 10.0. If A is less than 1.0, it is continually multiplied by 10.0 until

it is greater than 1.0.

USAGE:

CALL OVUN (A, B, I)

A = Input number to be transformed.

B = Part of B which is greater than or equal to 1.0

and less than or equal to 10.0.

I = The power of 10 which is associated with B to

form A.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

PFMULT

PURPOSE:

To generate a point field matrix, relating the steady deflections of the center of a blade segment to those of the previous segment center.

METHOD:

The point matrix is defined as W(5X5):

<u>Column</u>	1	2	3	4	5	Row
W =	$\overline{1}$	L/A	-L*J/2	-L ² *J/6	C*J*L/2 + L* _Y *B	1
	0	2/A-1	-J	-A*J*L*(1/A+0.5)/3	C*A*J*(B+2)+2* _Y *B	2
	0	-2B/(A*J)	1/A	L*(1/A+2)/3	-C*(B+6)-2*γ*B/(A*J)) 3
	0	.0	0	1	-L*D	4
	0	0	0	0	1	5

Where:

- 1) D = Thrust or drag derivative/unit length between segment centers.
- 2) EI = Flatwise or edgewise segment stiffness.
- 3) L = Segment length.
- 4) M = Segment mass.
- 5) R = Segment radial position.
- 6) r = Blade lag or coning angle.
- 7) Ω = Rotor speed.

8) A =
$$\left[1-L^2*\Omega^2/(2*EI)\right] * \sum_{i}^{N} M_i R_i$$

- 9) B = 1/A-1
- 10) $C = L^2 * D/12$
- 11) J = L/(EI*A)

For inplane deflections, a point mass matrix is added to the fourth row whose elements then become

$$W(4,I) = W(4, I) - M \times \Omega^{2} \times \left[W(1,I) + R \times_{\gamma} \times W(5,I)\right]$$

Conditions at the next center are obtained by premultiplying W by the matrix representing conditions at the previous center.

USAGE:

CALL PFMULT (PFIN, PFOUT, LS, AS, EIS, DS, MOMG2S, GAMOS, RS, ISWTCH)

PFIN = 5x5 matrix corresponding to previous center.

PFOUT = 5x5 matrix corresponding to next outboard center.

LS = Distance between centers.

AS = $\left[1-L^{2}\Omega^{2}/(2*EI)\right] * \sum_{i}^{N} M_{i}R_{i}$

EIS = Flatwise or edgewise second moment of area between centers.

DS = Thrust or drag derivative/unit length between centers.

MOMG2S = $M*\Omega^2$ (centrifugal force).

GAMOS = γ - calculated lag or coning angle.

RS = Distance of next center from the blade root.

ISWTCH = 0 for inplane deflections.

= 1 for out-of-plane deflections.

SUBROUTINES CALLED:

GMPRDD

ERROR RETURNS:

None

RESTRICTIONS:

PICK

PURPOSE:

Given 3 points on the curve y=f(x), choose the best 2 to use for an estimate of the solution of y=f(x).

METHOD:

The 3 points are rearranged such that

$$y_1 - x_1 \ge y_2 - x_2 \ge y_3 - x_3$$

If $y_2 - x_2 \le 0$, then points 1 and 2 in the rearranged order are used.

If $y_2 - x_2 > 0$, then points 2 and 3 in the rearranged order are used.

USAGE:

CALL PICK (TT, CT)

TT = Array of argument values.

CT = Array of function values.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

PINT

PURPOSE:

To print the input data used in the blade natural frequency and mode shape calculations.

METHOD:

If the print option is set to 4, the input is printed. Otherwise, control is returned to MODES with no

printing.

USAGE:

CALL PINT

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

POUT

PURPOSE:

To print the output of the blade mode subsegment of the

program.

METHOD:

This routine is not used by the rotor stability program, but has been included for completeness.

USAGE:

CALL POUT

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

PRELIM

PURPOSE:

To prepare the data for use by the rotor aeroelastic analysis.

METHOD:

The two main tasks of PRELIM are to standardize the data tables so that all the data tables are defined over the same segment lengths or at the same radial points, and to control the calculation of other quantities needed throughout the remainder of the program.

Transfer of data between the program segments is achieved through 3 COMMON blocks. Blank COMMON is used primarily to store input data. Quantities calculated by PRELIM from the input are stored in labelled COMMON/DYNINP. Printout control is maintained by switches set in labelled COMMON /PRNTSW. All other labelled COMMON blocks are used for the transfer of data within the PRELIM segment.

The following is a more detailed breakdown of the tasks performed.

1. The input data are read into blank COMMON via subroutine LOADIT and immediately stored on a temporary work file (Unit 11). Prior to each subsequent case in the run, this temporary file is read into blank COMMON; thus, only those variables which differ from the previous case need be input.

It should be noted that PRELIM is the third computer dependent routine due to different requirements for reading input data. Coding for both IBM and CDC systems is retained in the program with the appropriate lines commented out.

The coupling matrix terms needed for the bifilar analysis portion are initialized to zero to start. For subsequent cases, the coupling matrices are retained and used again if the rotor is not changed or recalculated if a new rotor is employed.

- 3. Specific input locations are set for the coupling with the bifilar analysis portion.
- 4. Control switches are set and, where applicable, inputs are converted from generally accepted engineering units to standard units for program calculations.
- 5. The input blade segments, which form the basis of all radial distributions used by the program, are adjusted to include a 0.1 segment to accomodate pitch horn effects. They are then used to set up a radius vector representing the distance of the mid-points of each segment from the center of rotation. The offset is automatically included if it exists.
- 6. All input tables are extended or redefined over the distributions obtained in 3 above.
- 7. Pitch horn effects are added to the blade center of gravity and blade weight tables.
- 8. The thrust for the input pitch angle is calculated for hover or vertical flight.
- 9. An input vector used by MODES to calculate mode shapes and frequencies is set up. In multiple cases, if this input has not changed from the previous case, then no call is made to MODES and the program uses the values obtained in the previous case.
- 10. Pitch-lag and pitch-flap coupling effects are calculated using the blade bending modal components at the pitch horn.
- 11. Blade lag damper coupling terms are calculated from the input blade damper geometry.
- 12. The aerodynamic derivatives and steady deflections are calculated in hover.
- 13. Control system inputs are checked to eliminate contradictions.
- Blade torsional properties are calculated including cross-beam blade characteristics.

15. Selected portions of the input and calculated data are printed out by subroutine PROUT.

USAGE:

CALL PRELIM (NCASE, NMODE)

NCASE = 0 Input vector, INPUT (8100), is initialized to zero and the rotor analysis title (first one) is read in.

Input vector is not set to zero, original input vector is read from Unit 11 and the first title card is not read in.

NMODE = Switch for calculating mode shapes and frequencies.

SUBROUTINES CALLED:

LOADIT, SORTAB, EXTEND, FILL, SECAER, QTFG, PICK, MODES, REMOVE, STDEFL, FOLL, FULL, E159X, PROUT

ERROR RETURNS:

None

RESTRICTIONS:

PRODM

PURPOSE:

To calculate the matrix relating blade forces, moments and elastic deformations at the tip to the blade root and to apply the boundary conditions.

METHOD:

Since the elastic matrices and twist transformation matrices are independent of the frequency, they are calculated once for each segment and stored on a work file. For the given frequency, the mass transfer matrices are calculated and combined with the matrices on the work file to produce the tip-to-root relation matrix. Boundary conditions are applied, and the resulting 8 X 8 matrix is returned.

Some data are stored in a temporary work file (Unit 8).

USAGE:

CALL PRODM (A, NEQ)

A = The returned 8 X 8 matrix.

NEQ = The dimensions of A.

SUBROUTINES

CALLED:

ELO, MATEO, MATR, ELI, MATEI, GMPRDD, MATF

ERROR RETURNS:

None

RESTRICTIONS:

PROUT

PURPOSE:

To print selected input and calculated quantities.

METHOD:

All significant input and calculated quantities are printed out depending on the setting of the print

switch.

USAGE:

CALL PROUT (NBLD, NSEG, IE, IF, GJ, T, BETOD, GAMOD)

NBLD = Number of blades.

NSEG = Number of blade segments.

IE = Blade edgewise second moment of area.

IF = Blade flatwise second moment of area.

GJ = Blade torsional stiffness.

T = Blade thrust.

BETOD = Blade steady coning angle.

GAMOD = Blade steady lag angle.

SUBROUTINES

CALLED:

SKIPLN

ERROR RETURNS:

None

RESTRICTIONS:

QTFG

PURPOSE:

To compute the vector of integral values for a given

table of argument and function values by the

trapezoidal rule.

METHOD:

This routine is a copy of QTFG, and is obtained from

IBM System/360 Scientific Subroutine Package.

USAGE:

CALL QTFG (X, Y, Z, NDIM)

X = The input vector of argument values.

Y = The input vector of function values.

Z = The resulting vector of integral values.

NDIM = The dimensions of X, Y, and Z.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

REMOVE

PURPOSE:

To delete a blade flatwise or edgewise mode from an

array of mode shapes and frequencies.

METHOD:

The characteristics of each mode are examined until the required mode is found. Then, the mode shape and

its frequency are deleted and the remaining modes

are compressed in the array.

USAGE:

CALL REMOVE (SHAPE, MODE, TYPE, N)

SHAPE = An array containing the type of each mode.

MODE = Number of modes to be examined.

TYPE = The type of mode to be removed.

= The occurrence of type which is removed,

i.e., the 2nd flatwise.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

A message is printed if the requested mode could not

be deleted.

RESTRICTIONS:

RHS

PURPOSE:

To shift the damping and stiffness contributions to the right-hand-side of the non-linear bifilar equations of motion.

METHOD:

The stiffness and damping matrices obtained at the completion of the calling sequence in SYSCTL are postmultiplied respectively by the initial values of the state variables displacements and velocities. The resulting vector, FRHS, is shifted to the r.h.s. by a change in sign and transferred through labelled COMMON/NLDAT2. It is dimensioned NRHS (see below).

USAGE:

CALL RHS (NRHS)

Total number of degrees-of-freedom not NRHS =

including number of non-linear bifilars

(maximum values is 60).

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

ROOTX

PURPOSE:

To calculate the blade elastic torsional mode shape.

METHOD:

The blade torsional mass moment of inertia and stiffness distributions are used to calculate the torsional mode shape using a given frequency trial and the

input value of rotor speed.

The frequency and mode shape trials are printed out

if location 119 is 6.

USAGE:

CALL ROOTX (W2, XHI, O2, YTI, YTK)

W2 = Square of frequency trial, (rad/sec)²

XHI = Calculated blade torsional mode shape,

non-dimensional

02 = Square of rotor speed, (rad/sec)²

YTI = Blade torsional mass moment of inertia,

in-1b-sec²

YTK = Blade torsional stiffness, $1b-in^2/in$

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

SECAER

PURPOSE:

To calculate blade section coefficients and derivatives.

METHOD:

Lift, drag, and pitching moment coefficients are input against angle of attack for various Mach numbers. For a given angle of attack and Mach number, the required coefficients and their derivatives with respect to Mach number and angle of attack are obtained from the corresponding table by linear interpolation.

The routine assumes airfoil data to be non-symmetric if the first input angle of attack value is negative.

For angles of attack greater than 30° , a Mach number of 0.0001 is assumed.

USAGE:

CALL SECAER (ALPHA, AMACH, I, M, FF, DFF, DM)

ALPHA = Angle of attack (radians).

AMACH = Mach number.

I = Not used by this program.

RFM = 1 for lift coefficient.

= 2 for drag coefficient.

= 3 for pitching moment coefficient.

FF = Returned coefficient.

DFF = Derivative with respect to angle of attack.

DM = Derivative with respect to Mach number.

SUBROUTINES CALLED:

BLIN4

ERROR RETURNS:

Any error termination from BLIN4 stops execution with the message 'TROUBLE IN BLIN4', followed by 6 numbers which represent angle of attack in radians, angle of attack in degrees, input Mach number, Mach number used, the error switch L from BLIN4 and the switch M respectively. See BLIN4 for description of errors.

RESTRICTIONS:

See locations 1850-4548 of rotor stability input description and BLIN4.

SHAKIT

PURPOSE:

To control the principal logic flow of the rotor/bifilar coupled program.

METHOD:

MAIN first calls subroutine PRELIM, which controls the input, conversion and adjustment of the blade data. Then, the rotor blade dynamic and aerodynamic matrices are obtained from calls to DYNMAT and AERMAT respectively. The dynamic and aerodynamic matrices are cleaned out, added together, compressed and stored for coupling with the bifilar analysis portion in EIGER. The bifilar analysis is subsequently executed by calling MAINSV.

After PRELIM is called, the rotor analysis calculations are bypassed if input location 110 is zero or -1.

It should be added that SHAKIT is the fourth computer dependent routine. For CDC use, the first line of code is

"PROGRAM SHAKIT (INPUT, OUTPUT, TAPE1, TAPE2, TAPE3)".

For IBM use, this card is not needed; thus, the first line contains blank COMMON input data.

USAGE:

Program SHAKIT is never referenced in a CALL state-

ment.

SUBPROGRAMS CALLED:

PRELIM, DYNMAT, AERMAT, EIGER, MAINSV

ERROR RETURNS:

None

RESTRICTIONS:

SIMLIN

PURPOSE:

To solve a system of linear simultaneous equations.

METHOD:

The solution is obtained by elimination using largest pivotal division. The determinant of the coefficient matrix is produced during the process.

USAGE:

CALL SIMLIN (A, B, X, N, NX, C)

A = Coefficient matrix (destroyed during computations) of dimensions XN by XN.

B = Vector of right-hand value, destroyed during the computations. On return, B(1) contains the determinant of the coefficient matrix.

X = Solution vector.

N = The number of rows in A.

NX = Dimensions of matrix A.

C = Work vector.

SUBROUTINES CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

SKIPLN

PURPOSE:

To skip a given number of lines during printing.

METHOD:

In an effort to prevent the printout of output tables going over a page boundary, SKIPLN is used to center tables within a page or part of a page.

USAGE:

CALL SKIPLN(J)

J = Number of lines to be skipped.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

SORTAB

PURPOSE:

To unscramble an array of alternating X and Y points into an array of X points and an array of Y points.

METHOD:

Even subscripted values in the input array are moved to another array. Both arrays are then compressed.

USAGE:

CALL SORTAB (G, M, KSTAR, NSTAR)

G = On input, G contains the alternating X and

Y values.

On output, G contains only X values.

M = The number of points in G on input.

KSTAR = The unscrambled Y points.

NSTAR = The number of points in G and KSTAR on

output.

SUBROUTINES

CALLED:

None

ERROR RETURNS:

None

RESTRICTIONS:

STDEFL

PURPOSE:

To calculate the inplane and out-of-plane blade steady deflections and slopes.

METHOD:

Blade deflections are calculated by successively calculating the deflection of each segment relative to the previous one. This is done by constructing a point matrix from the mass, stiffness, and geometric properties of the segment to relate the displacement of the center of a segment relative to the previous center. The process is started by assuming suitable conditions at the root of the blade. A correction is made to these deflections if the pitch bearing does not follow the blade root slope.

USAGE:

CALL STDEFL (QEO, XEO, E, RB, MB, NB, RR, D, IE, IF, TH, OMEGA, EB, GAMOT, KGAMA, GAMO, KASE, IEF, ROTDEF)

QEO = Returned inplane or out-of-plane steady deflections.

XEO = Returned slope for inplane or out-of-plane
deflections.

E = Blade offset.

RB = Array of distances of the blade segment centers from the center of rotation.

MB = Mass of each segment.

NB = Number of radii in RB.

RR = Blade segment lengths.

D = Drag derivative for inplane deflections or thrust derivative for out-of-plane deflections.

IE = Blade edgewise second moment of area.

IF = Blade flatwise second moment of area.

TH = Blade twist.

OMEGA = Rotational speed.

EB = Blade Young's modulus.

GAMOT = Calculated lag angle for inplane deflections or calculated coning angle for out-of-plane deflections.

KGAMA = Blade lag hinge spring constant for inplane deflections or blade flapping hinge spring constant for out-of-plane deflections.

GAMO = Blade prelag angle for inplane deflections
 or blade precone angle for out-of-plane
 deflections.

KASE = Blade pitch input control (derived from input location 115).

IEF = 0 for inplane deflections.

= 1 for out-of-plane deflections.

ROTDEF = Rotor definition (input location 114).

SUBROUTINES CALLED:

PFMULT

ERROR RETURNS:

None

RESTRICTIONS:

SYSCTL

PURPOSE:

To include the contributions of the fixed system modes, rotor (if used), the fixed system absorbers and the linear inplane and vertical bifilars to the final system mass, damping and stiffness matrices in the bifilar analysis.

METHOD:

At first, SYSCTL calls FIXSYS to obtain the fixed system modes matrices. Then, if rotor contributions are desired, it restructures the rotor matrices and adds the rotor elements to the fixed system matrices using ADDOFR. Subsequently, it includes contributions due to fixed system absorbers from FIXABS, linear inplane bifilars from LINBIF and finally linear vertical bifilars from LVBIF. In all cases, the matrices are increased systematically by repeated calls to ADDOFR.

Printout of the matrices is governed by the switches

in locations 17 and 1490 through 1496.

USAGE:

CALL SYSCTL

SUBROUTINES CALLED:

FIXSYS, ADDOFR, FIXABS, LINBIF, LVBIF

ERROR RETURNS:

None

RESTRICTIONS:

REFERENCES

- 1. R. A. Johnston, "Helicopter Rotor Stability Analysis", USAAMRDL-TR-75-40, January 1976.
- 2. R. Piziali, "An Investigation of the Structural Dynamics of Helicopter Rotors", USAAVLABSTR-70-24, April 1970. AD872715.

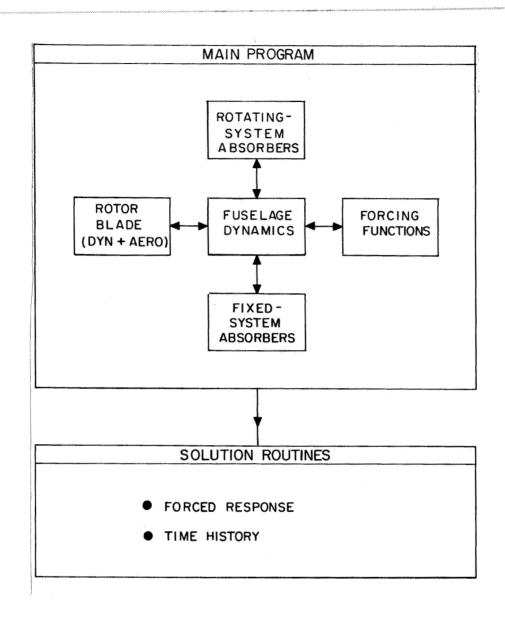


Figure 1. Block Diagram of Bifilar Analysis.

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FIGURE 3. Output Format - Rotor Blade Characteristics.

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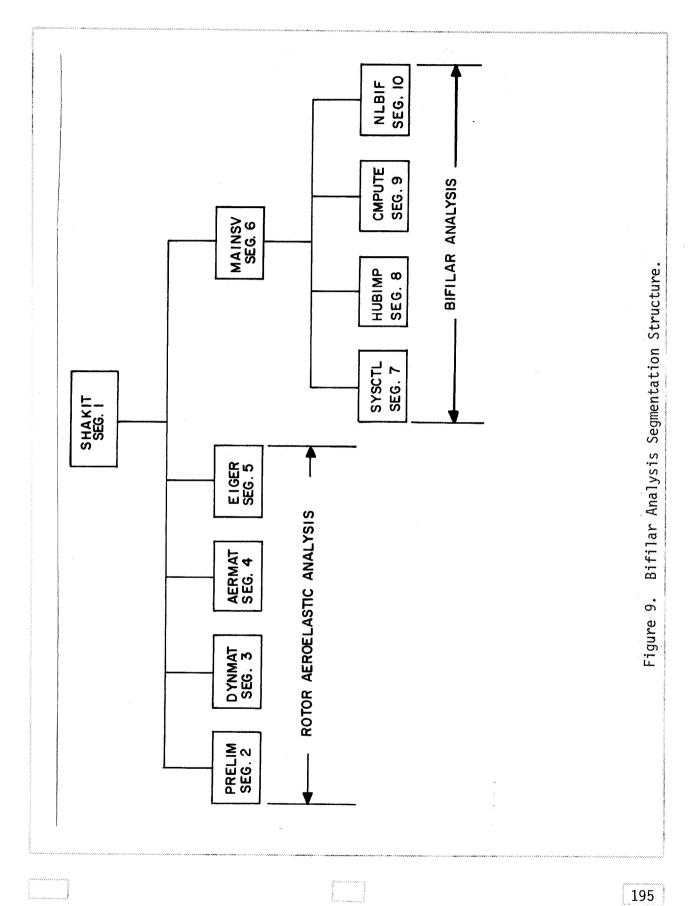
.341720-11 .264490-08 -49520-11 -197540-08 -409920-11 -317280-08 FIXED SYSTEM + ROTOR + FIXED ABSORBERS (R.H.S.) OF GROER 25 (PSI = 2 DEG)
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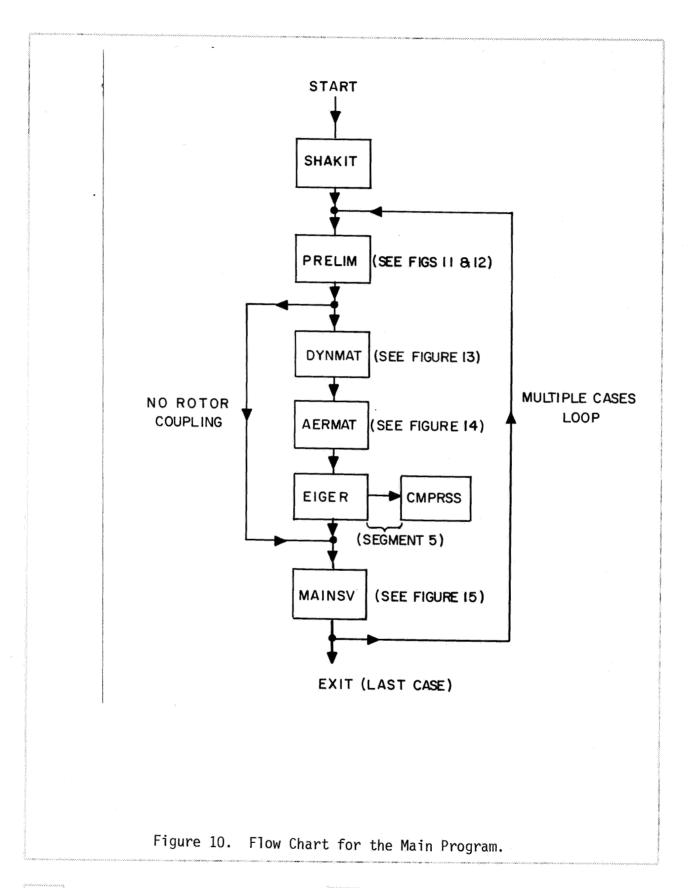
NEEVE 5, 61=4620-92, 62=3400-91, 781633320-92, 781083500-92, 782191320-94, DONUGS770, , DTRUGS4660-91. NEEVE 6, 61=1260-91, 62=3210-91, 281033210-92, 781083210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193210-92, 782193220-92, 782193220-92, 782193220-92, 782193220-93, 78219 .	(f) FIGURE 7. Concluded.
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	17284D-03 11495D-03 .20757D-03	40974D-03 54539D-03 .68215D-03 -126.92	31934D-01 31934D-01 .99998D-01 -18.623	.988150-02 .164420-02 .100170-01 9.4468	-,19251D-03 -,19251D-03 -,21919D-03 -61,433	62883D-04 16556D-04 .65026D-04 -14.750	.22167D-03 22391D-03 .31522D-03 -45.263	.3672D-04 .3031ID-04 .49135D-04 38.090	
3 -,18544D-03 -,20083D-04 -,18653D-03 -173.82	12456D-03 20787D-04 -12629D-03	20801D-03 10326D-03 -23223D-03 -153.60	.49658D-02 65451D-02 .82157D-02 -52.813	.29709D-02 .67828D-02 .74049D-02 66.346	.362470-03 107170-03 -377980-03	.16057D-03 29909D-04 .16333D-03	.73182D-04 29406D-04 .78869D-04 -21.891	.68470B-04 36232D-05 68569-04	
4 .,11692D-09 -,34145D-05 .12131D-04 -16.279	.18351D-04 .35567D-05 .18692D-04 10.969	.20934D-04 17642D-05 .21008D-04	10088D-02 27056D-03 .10444D-02 -15.013	.25708D-0365194D-0370080D-03 -68.479	-,40229D-04 -,96333D-05 .41367D-04	18089D-04 43971D-05 .18615D-04	637360-05 - 425160-05 . 766150-05 - -146.29 .	222840-05 222840-05 .807450-05 -163.98	as then prior stand and arith
520246D-04 .57440D-06 .20254D-04 .178.37	28300D-04 19054D-05 28364D-04 -176.15	39290B-04 77411B-05 -40045B-04 -168.85	.11809D-02 25992D-02 .28599D-02 -65.566	.32143D-03 .67686D-03 .74930D-03 64.598	.43543D-04 17481D-04 .46921D-04 -21.874	.20206D-04 75718D-05 - .21578D-04 -20.543 -	.177030-04 611790-05 .187310-04	.86785D-05 33195D-05 .92917D-05 -20.932	And the second s
. 6 .12641D-05 - .17520D-05 - .21604D-05 - .54.189 -	.79781D-0 .63593D-0 .10202D-0	.281540-05 .175880-06 .282090-05 3.5747	-03	222		5427910-06176810-06 5101640-05193280-05 5 .110280-05 .194110-05	.17881D-06 .19328D-05 - .19411D-05	218270-06 46859D-06 51694D-06 -65.024	IBM 230687
	FIGURE 8.	. Output F	Format - Bi	Bifilar Non	Nonlinear Ana	Analysis Tim	Time History	Results.	

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1 P 2 P 3 P 4 P 5 P 6 P 7 P 1 P 2 P 3 P 4 P 5 P 6 P 7 P 1 T746460-06 10550-04 455770-05 105370-01 1151420-02 1177800-03 117780-01 117280-01 115780-04 455770-04 115780-01 115780-02 117780-01 115780-03 117780-01 115780-02 117780-01 1177		morningerstraffer of typical	Adventures to the second of the	a. 80	.77459D-04 .72264D-05 ,77795D-04 174.67	10032D-03_ 12696D-04 .10112D-03 -7.2126				99222D-04 .17450D-04 .10074D-03	.14243D-03 23445D-03 .27432D-03	571370-05 .123360±03 .123500-03	A MATOTON LEET LEEK MATOTON TO LEET LEEK LEEK LOOK OF LEET LEEK LOOK OF LEET LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF LEEK LOOK OF
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1 P 2 P 3 P 4 P 5 P		Andreas Andrea			13784D-03 87238D-05 13811D-03 -176.38	.153840-03 .153840-03 .574520-03 15.532		POINT	9	18505D-03 .37913D-04 .18689D-03 168.42	.599690-03 769270-03 .975390-03	.159870-03 .692820-03 .711020-03 77.007	POINT (b)
USERATION LEVELS AT 4 A/C LOCATIONS. 1 P 2 P 3 P 4 P 1 T4646D-04 .10540D-03 .16495D-03 .68218D-0217197D-04 .10159D-04 .45374D-04 .16037D-0127464D-05 .10159D-04 .45374D-04 .16037D-0127640D-03 .23746D-03 .17428D-03 .17354D-0127545D-04 .10580D-03 .17428D-03 .27544D-0127545D-04 .10580D-03 .17436D-03 .13519D-0127545D-04 .10590D-03 .13519D-01 .27545D-04 .10098D-03 .13519D-0127545D-04 .10590D-03 .15625D-03 .13519D-0127545D-04 .10098D-03 .13519D-01 .16495D-0127545D-04 .101098D-03 .13519D-01 .16495D-0127545D-05 .27546D-03 .57717D-03 .14695D-02172.01 .10408D-03 .14140D-03 .21754D-03 .50184D-0227640D-03 .14140D-03 .21754D-03 .67374D-0227640D-05 .14146D-03 .22073D-03 .19622D-0128095 .16413D-03 .22073D-03 .12647D-0239016D-03 .14146D-03 .22073D-03 .12647D-0128905 .15339 .9.7465 .110.1009039016D-03 .14146D-03 .22073D-03 .12647D-0239016D-03 .14146D-03 .22073D-03 .12643D-0126493D-03 .24459D-03 .12643D-03 .12643D-0126493D-03 .24459D-03 .12643D-03 .12643D-0126493D-03 .24459D-03 .12643D-03 .12643D-0126493D-03 .24459D-03 .12643D-03 .12643D-0111933D-03 .24459D-03 .12643D-03 .12643D-03116485SINE,TOTAL AMPLITUDE IN 6 AND PHASE ANGLE		in the second se	IN DEGREES.		17800D-03 15142D-02 15246D=02 -96.705	-,26798D-02 ,88283D-02 ,92260D-02 106,89	-, 381450-02 , 924170-02 , 999800-02	DEGREES	1	-,71084D-03 -,22860D-02 -,23939D-02 -107.27	.96273D-02 .11193D-01 .14763D-01 49.299	12303D-01 .86053D_03_ .12333D-01 176.00	DEGREES
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			COSINE,SINE,		' '	44641B-03 20551D-03 .49145D-03 -155.28	-,218250-03 -,275450-04 -,219980-03 -172,81	COSINE, SINE, 1	1		-,79428D-03 -,39016D-03 .88493D-03	.11722D-03 .22443D-04 .11935D-03 10.839	COSINE, SINE, T
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1720-1739)	(LC.1740-1759)	3.5655	(1C.1788-1773)	.45858D-04	(LC.1774-1779)	330850-02	780-1859)	.38650D-02 .38200D-03 11073	960-1939)	.15078 -1.2027 5.2717		-				***************************************
R DISPLACEMENTS (LC.1720-1739)	1	-13.417		.259740-03		10-066291	ARIÁBLES DISPL.(LC.1780-1859)	.47216D-04 .31296D-07 .20740D-01	INITIAL_STATE_VARIABLES. VELOC, (LC.1860_1939)_	21021 11013D-04 - 2,7402						* *************************************
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34889D-01165	INITIAL B	13, 328	INITIAL	.15065D-02	INITIA	-,43641	INITIAL STATE	-,41930D-04 -,47164D-04 -,13830D-04	- INITIAL S	.47650D-01 10169 79445D-02	1					





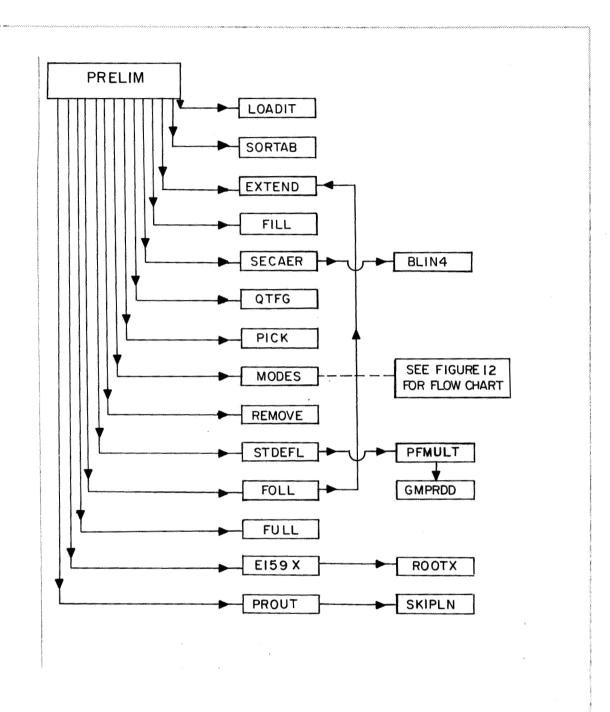


Figure 11. Flow Chart for Subroutine PRELIM.

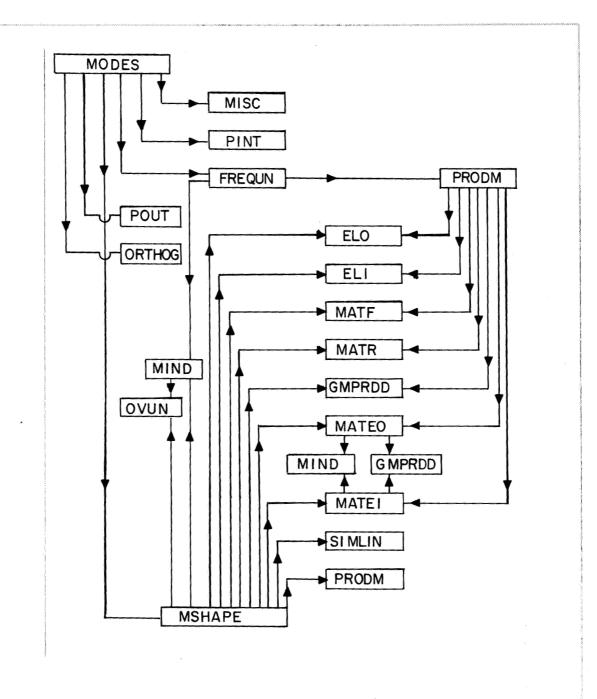


Figure 12. Flow Chart for Subroutine MODES.

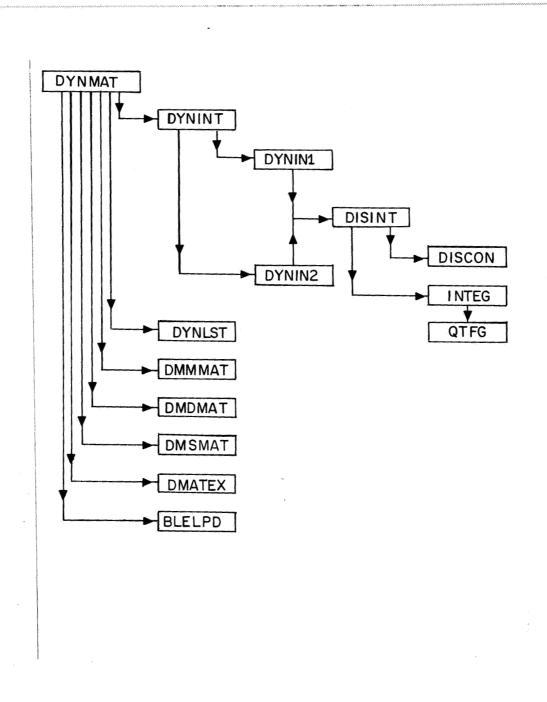


Figure 13. Flow Chart for Subroutine DYNMAT.

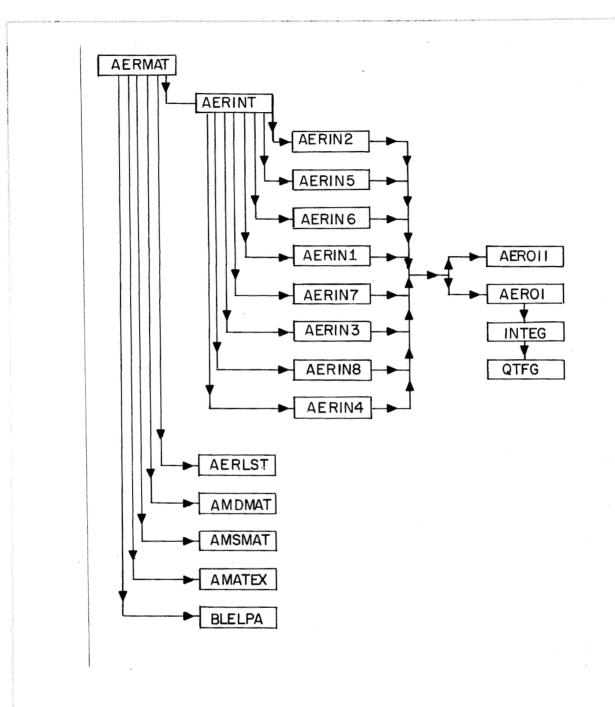


Figure 14. Flow Chart for Subroutine AERMAT.

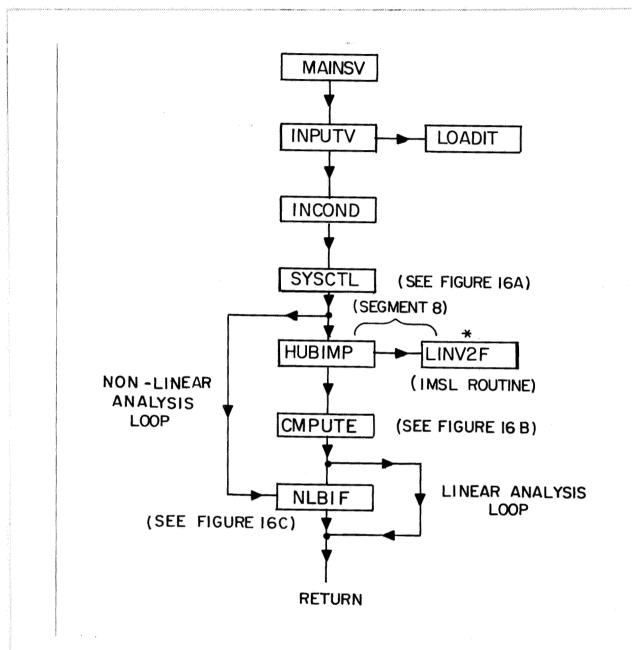


Figure 15. Flow Chart for the Bifilar Analysis.

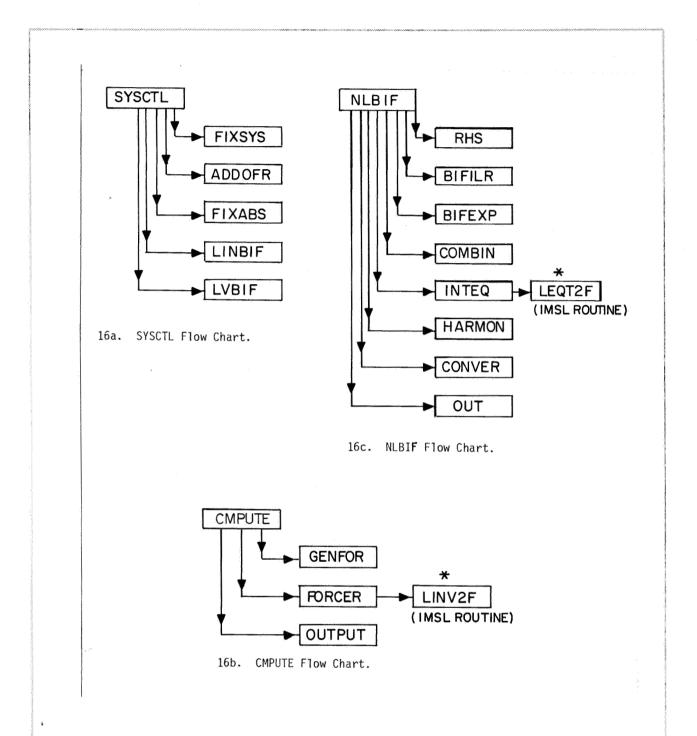


Figure 16. Flow Charts for Subroutines SYSCTL, CMPUTE, NLBIF.

		SUBROUTINE COMMON BLOCK	BLANK AERO1 AERO2 AERO3 AERO3 AERO3 AERO4 AERO5 COCAER CONT DAT DAT DAT DAT DAT DAT DAT DAT DAT DA	
	88 89 90 91 92	STDEFL SORTAB SKIPLN	× ××× × × × × × ×	
	83 84 35 86 87	SHAKIT SECAER ROOTX RHS REMOVE	× × × × × × × × × × × × × × × × × × ×	·
	77 78 79 80 81 82	PROUT PRODM PRELIM	*	
	72 73 74 75 76	PICK PFMULT OVUN OUTPUT OUT	× × × × ×	
	66 67 63 69 70 71	MODES MISC	* * * * * * * * * * * * * * * * * * *	(a)
	0 61 62 63 64 65	MATEI MAINSV	× × × × × × ×	
	55 56 57 58 59 60	LVBIF LOADIT LINBIF INTEQ INTEG INPUTV	× × × × × × × × × × × × × × × × × × ×	•
	50 51 52 53 54	INCOND HUBIMP HARMON GMPRDD GENFOR	× × × × × ×	
	46 47 48 49	FULL FREQUN FORCER FOLL	× × × × × ×	ety.
		SUBROUTINE COMMON BLOCK	BLANK AERO3 AERO3 AERO3 AERO3 AERO4 DOJAT DOYAUT DOYAUT DOYAUUT EMATO INCIGN INCICN INCIGN IN	
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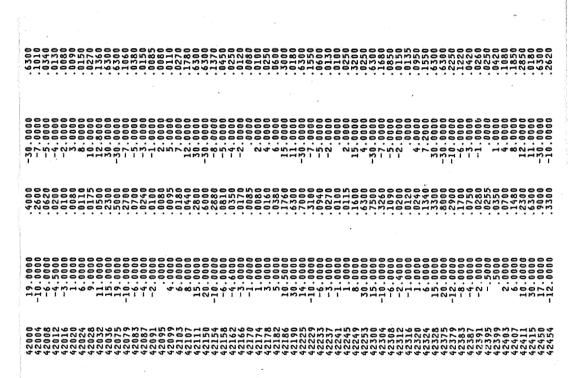
Figure 17. COMMON Blocks.

	SUBROUT INE COMMON BLOCK	BLANK AERO1 AERO3 AERO3 AERO5 COCAER	DATI DAYNINP DYNOUT EMAT1 EMAT0	FDF6 FPAT FREQ HARM HARM INDAT INEIG LAGDAM KAMIC KDOF NIMIC NIMIC	NLDA12 NLDA12 PHTNO PHAT PRAM1 PRSNTH TMDS	TORFIN TOTMAT TWISTM WORKA XFRDAT
3 44 45	FIXSYS FIXABS			× × × ×		× ×
1 42 43	FILL E159X	×	×		×	*
40 41	EXTEND ELO		×		·×	×
39 7	ELI		×		×	×
38	EIGER	×	×	×		
37	DYNMAT	×	××	**		
5 36	DYNLST	×	**		A.A	
34 35	DYNIN2 DYNIN1	×	×× ××	× ×	× ×	
33 3	DYNINT	×	××			
32	DMSMAT	×	××	× ×		
31	DMMMAT	×	××	×		
30	DMDMAT	×	×	× ×		
28 29	DMATEX			**		
27 2	DISINT					
56 2	CONVER			×		
25	COMBIN			×	×	×
24	CMPUTE			*		
2 23	CMPRSS					
21 22	BLIN4 BLELPD	×	××	××	×	
20 2	BLELPA	×××××	×	×		
19	BIFILR			* *	×	
138	BIFEXP			* *	×	× '
17	AMSMAT	****	×	×		
15 16	AMDMAT AMATEX	***	×	× ××		
14 1	AEROII	*				
13]	AEROI	×				
12	AERMAT		×	××		
=	AERLST	***	×	×	× ×	
9 10	AERIN8	××××××	× ×	~ ×	×	
8	AERIH7 AERIN6	*****	× ×	×	×	:
_	AERIN5	×××××	×	·×	·×	•
9	AERIN4	×××××	×	×	*	
5	AERIN3	****	×	× ×	×	
4	AERIN2	*****	×	~ ×	×	
2 3	AERIN1 AERINT	××××××	×			
	ADDOFR			× ×		× ×
L	l ,		· · · · · · · · · · · · · · · · · · ·			
annonno con managara de proposaciones de annimados de la calenda de la c	SUBROUTINE COMMON BLOCK	BLANK AEROZ AEROZ AERO3 AERO4 AERO4 AERO4 CDCAER			N LDA11 N LDA12 N PHTMO N PRATI PRAM1 PRAM1 PRAM1 PRAM1 PRSWTH	·
	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	1284397	261121	2432 222 233 2433 2433 2433 2433	272 278 30 30 319 32	35.33

			} ;								
INPUT DATA	SYS OPTION SYS OPTION SYS OPTION SYS OPTION	(5 MAXIMUM) (RIGHT ADJUSTED)	9012345678901234567890	20.08	ic.		.355	16.8 17.49 15.9			
APPENDIX B. TEST CASES	010R - LINEAR 010R - LINEAR ANA 010R - NON-LINEAR ANA 010R - NON-LINEAR ANA 010R - COUPLED PROGR	INTEGER INTEGER, REAL REAL REAL REAL REAL REAL REAL	2345678	•	7.25		6.82	16.8 17.49 15.9	8.3 20.76 22.317 20.76	-9.5 2.8 1.2	1.2
		BIFILAR COUP D E, F, G NO. OF ITEMS LOCATION NO. QUANTITY , QUANTITY , QUANTITY , QUANTITY ,	COLUMN NUMBER 6789012345678901	66	4. 15.1265 1.	11.	9.178	255 115.9	15. 50. 228.96 276.66 322.	50. 318.	50. 318.
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	CASE I. AU	KUIUK KESULIS		
F	TITLE 1 - TEST MAIN ROTOR	DATA - COUPL	- COUPLED WITH BIFILAR ANALYSIS	000463
HOVER	THE PROPERTY OF THE PROPERTY O	Contractor and constitution of a Distance of the Contractor of the	AND THE STREET WASHINGTON TO COMMON THE STREET WASHINGTON THE STREET WASHINGTON TO STREET WASHINGTON TO STREET	
MAIN ROTOR				
PITCH ANGLE AT 75% RADIUS	L 75% RADIUS		6.400 DEG	-
CALCULATED THRUST	พรา	= 1636	16364.911 LB	
CALCULATED CONTING ANGLE	IING ANGLE	11	3,389 DEG	
CALCULATED LAG ANGLE) ANGLE	,n	5.180 DEG	
CALCULATED BLA	CALCULATED BLADE TORSTONAL FREQUENCY	Harry new cons	0.0 RAD/SEC	
CALCULATED BLA	CALCULATED BLADE BENDING FREQUENCIES :	MODE 1 =	77.5 RAD/SEC	
APPROPRIATE TO THE PROPERTY OF	етт галаларов, г. п. п. паналаров гд. панадароваров, по панадароваров по панадароваров по панадароваров по пан	MODE 2 = 12	126.7 RAD/SEC	
RADIUS (IN)	STEADY DEFLECTIONS	IONS (IN) EDGEWISE	ANGLE OF ATTACK (DEG)	
0.0	0.0	0.0	-74.100	
15.000	0.0	0.0	-33.210	
41.250	-0.00- -0.00-	0.011	-20.206	
62.500	0.041	0.285	-0.199	
93.400	0.156	0.505	2.542	
117.000	0.356	0.904	3.650	
133.800	0.455	1.119	4.447	-
150.600	0.546	1.343	4.446	
185.235	0.020	1.582	4.277	
202.725	0.723	2.098	3.588	
220.215	0.728	2.371	3.124	
236.910	969.0	2.641	2.627	
268.710	0.542	706.30	7 2 110	
283.145	0.456	3.437	1.5.1	
296.115	0.397	3.670	-0.156	
306.450	0.368	3.857	-0.345	
314.150	0.353 0.344	3.997	1.279	
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ement enter come trans trans trans trans trans trans and enter a transit trans	PHOS	and the contract cont	ROTOR SPEED BLADE RADIUS R.P.M. FEET	256.0000 26.83333	PRELAG ANGLE PRECONE ANGLE RADIANS	0.0	REF. ROTOR SPEED BLADE BENDING MODES	258,00000 2	PITCH BEAM SIJFENESS ACTUATOR MON. STIFENESS _PITCH_BEAM RADIUS_ LB/IN. INCHES	0.0	LAG DAMPER COEFFICIENT LAG DAMPER STIFFNESS FLEXBEAH ROOT (XBR) LB-SEC/IN. INCHES	0.0	обуства на надажения в надажения в надажения в надажения в надажения в надажения в надажения в надажения в над	ARTIC	the same seems were the same seems that same many than	MRMASC	1.11.	
PHFLD PHFPLD 0.0 0.0 0.0	PHLD THTLD	Water and the second	AXIAL VEL. KNOTS	0.0	ROOT LAG SPRING LB.IN./RAD.	0.0	RIGID PITCH DAMP. FRACT CRITICAL	0.0	ITCH BEAM STIFFNESS LB/IN.	0.500000+05	AG DAMPER COEFFICIE LB-SEC/IN.	676.00000	WITCHES	ROTDEF	· · · · · · · · · · · · · · · · · · ·	TSERVC	1.	
PHEPLD 0.0	GFOPLD .	i	TIP LOSS FACTOR	0.99000	ROOT FLAP SPRING LB.IN./RAD.	0.0	LAG DAMPING FRACT CRITICAL	0.35000		0.0	ELASTIC PITCH DAMP. L FRACT. CRITICAL	0.0	CONTROL SWITCHES	SYSDEF	0 1000111.	SUMASC	111.	
PHIZPH PHELD 0.0 0.0 0.0010 0.0	GEOPLD GFOLD	-	SPEED OF SOUND FT./SEC.	1116.00000	NUMBER OF BLADES	***************************************	RADIUS OF PUSH ROD INCHES	15.12650	EIXED SYSTEM HODES PITCH-LAG COUPLING WEIGHT AT PUSHROD,	0.0	FORWARD FLIGHT SPEED KNOTS	0.0	s de de company es es es de decembrance es es és de decembrance es es est de decembrance es es de decembrance	FTEST		TRMASC	1.	
MODE NO. PHIXPH 1,0000.	GEOLD A COLD		AIR DENSITY LB.SECSQ/IN.4TH	0.11468D-06	OFESET.	1.25000	JNG'S MOD. 3/INSQ	0.100000+07	EIXED SYSTEM MODES	Ŗ	PITCH HORN LENGTH INCHES	7.25000	AND THE PROPERTY OF THE PROPER	ROTEST		VECT	description of the description o	

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-0.00151	-0.00127	0.00444	0.00453	0.00450	0.00420	0.00351	0.00256	0.00133	-0.00032	-0.00215	-0.00418	-0.00600	-0.00672	-0.00611	-0.00370	-0.00217	-0.00171		TV07(H0)0		0.0	-0.00001	0.00034	0.00109	0.00107	0 00100	0.00096	0.00100		0.00095	0.00083	0.00078	00000	0.00084	0.00055	0.00039	0.00079	0.00168	0.00288
0.00155	0.00659	0.01101	0.01170	0.01231	0.01290	0.01347		0.01460	0.01516	0.01577	0.01635	0.01689	0.01741	0.01779	0.01806	0.01815	0.01816	01816	D(DT)/DOT.	0.0	0.0	0.33155	6.52470	23.85057	41.71577	81 93657	105.97988	134.44925	169.58604.	210.32202	255.52919	304.00663	201.427.70	541.85065	593.92714	697.52874	771.89581	817.74876	756.49209
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0.01108	0.10392	0.50523	0.69939	0.90412	1.11881	1,34309		1.83470	2.09751	2,37055	2.64091	5.90709	3.18148	3.43658	3.66970	3.85694	3.99675	4.10300	D(DT)/DUT	0.0	0.0	-0,000,0-		0.00414	0.00610	0.0042	0.00954	0.01102	0.01195	0.01269	0.01218	0.01210	0 01276	0.01276	0.00878	0.00549	0.01024	0.01896	0.02305
23.75000	41.25000	83.40000	100.20000	117.00000	133.80000	150,60000	167.74500	185.23500	202.72500	220,21500	236.91000	252.81000	268.71000	283.14500	296.11500	306.45000	314.15000	320.00000	~	0.0	15.0000	23.75000	41.25000	62.50000	83.40000	100.5000	133.80000	150.60000	.16Z.74500.	185.23500	202.72500	220.21500	252 81000	268.71000	283,14500	296,11500	306.45000	314.15000	320,00000
	0.01108 -0.00402 0.00155	0.01108 -0.00402 0.00155 - 0.10392 -0.00914 0.00659 - 0.00618	0.01108 -0.00402 0.00155 0.10392 -0.00914 0.00659 0.28471 0.04123 0.00918 0.50523 0.15567 0.01101	0.01108 -0.00402 0.00155 -0.10392 -0.00914 0.00659 -0.28471 0.04123 0.00918 0.59523 0.5557 0.0101	0.01108 -0.00402 0.00155 - 0.10392 -0.00914 0.00659 - 0.28471 0.04123 0.00918 0.50523 0.15567 0.01101 0.0939 0.25565 0.01170 0.90412 0.35611 0.01231	0.01108 -0.00402 0.00155 - 0.10392 -0.00914 0.00659 - 0.28471 0.04123 0.0059 - 0.5023 0.15567 0.01101 0.09399 0.25565 0.01170 0.90412 0.35611 0.01231 1.11891 0.45498 0.01290	0.01108 -0.00402 0.00155 - 0.10392 -0.00914 0.00659 - 0.28471 0.04123 0.00918 0.5023 0.1556 0.01101 0.69539 0.28566 0.01170 0.996412 0.35611 0.01231 1.11881 0.45498 0.01290	0.01108 -0.00402 0.00155 - 0.10392 -0.00914 0.00659 - 0.28471 0.04123 0.0059 - 0.5923 0.1557 0.01101 0.5939 0.25555 0.0170 0.99412 0.35511 0.01231 1.11881 0.55498 0.01390 1.38182 0.55655 0.01340	0.01108 -0.00402 0.00155 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	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
	15.00000	0.0	0.0	0.0	0.0	0.0	0.0			
	23,75000	0.00044	0.00073	-0.26554	-0.29732	-0.05191	0.31267			
	41.25000	-0.00948	0.02382	-30.98563	-0.42541	-0.11705	0.28950			
	62.50000	0.00011	0.00040	-0.62797	0.43651	0.15563	0.19019			
	83.40000	0.00014	0.00051	-1.08320	2.76489	0.63633	0.27625			
	100.20000	0.00017	0.00060	-1.54369	5.12602	0.97658	0.36383			
4	117.00000	0.00111	-0.00514	16.77181	7.77250	1.27528	0.54370		***************************************	***************************************
	133.80000	0.00120	-0.00588	21.82340	10.56367	1.53142	0.79426			
	150.60000	0.00351	-0.00625	27.06373	13.41433	1.74900	1.17383			
	167,74500	0.00455	F1900.0-	29 04084	14 63466	1 052.03				
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	202 72500	10000	0000	20 45440	17.55134	6.12254	4.59828			
	000.000	10000	000000	21404.00	22.08643	2.22559	6.18703			
	00013.033	/0T00.0-	*CC00.0-	19.00104	23.68544	2.24479	5.50461			
*****	236.91000	-0.00210	-0.00102	5.55483	26.25026	2.37083	5.39755			***************************************
	252.81000	0.00324	-0.00014	2.46406	26.27911	2.30451	5.25127			
	268.71000	0.00322	-0.00493	37.29655	25.32963	2.20955	6.39222			
	283.14500	0.00180	-0.00851	65.92044	16.95756	1 59790	20004			
	296.11500	0.00052	-0.01268	101.65111	A 78500	1 12949	111111			
	306.45000	-0.00627	-0.01825	148 14500	7 60476	77750	70076	***************************************	***************************************	
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	0.0	-0.42808	1.88000	0.47020	-0.74305	0.0	-0.30558	0.0	0.0	0.0
-	15.00000	-0.95837	0.74466	0.17059	-0.74305	-2.04628	-0.47995	0.0	0.0	0
	23,75000	-0.90206	0.44392	0.12548	0.57296	-1.08862	-0.10657	0.0	0.0	0.0
	41.25000	-0.62922	0.08167	0.05016	9.31056	-2.06265	-5 36861			
	62.50000	0.12646	0.00913	0.00251	6.76090	-0.03820	-0.00828			
	83,40000	0.44991	0.00964	0.00211	6.76090	0.01432	-0.00828			
	100.20000	0.58070	0.00991	0.00195	6.76090	0.01432	-0.00828	0.0	0.0	
	117.00000	0.64789	0.01013	0.00215	6.76090	0.03438	0.06646			
	133.80000	0.67479	0.01027	0.00242	6.76090	0.03438	0.06646	0.0		
-	150.60000	0.67739	0.01025	0.00283	6.78151	0.03460	0.06529	0 4824R	-0 00304	0 07119
	167.74500	0.67371	0.01004	0.00511	6.90300	0.03591	0.05834	0.47210	-0.00315	0.07172
-	185.23500	0.65383	0.00974	0.00736	7.02707	0.03627	0.04747	0.45377	-0 00342	0 07250
	202.72500	0.61704	0.00937	0.00829	7.13287	0.03870	0.04078	0.06675	10000	10 05041
	220.21500	0.56106	0.00897	0.00625	7.19546	0.04038	0.0234	0 05242	10000	10.000
_	236.91000	66665.0	0.00854	0.00459	7.25523	0.04000	0.00472	0.03691	-0.00363	-0.04489
	252.81000	0.43973	0.00838	0.00392	7.48130	0.07675	0.00184	0.35840	0.02610	0.01686
	268.71000	0.37532	0.00850	0.00423	8.02034	0.04954	0.02468	0.19908	0.01148	1,010.0
-	283.14500	0,24346	0.00800	0.00379	8.50984	0.0	0.04541	-0.07334	6	-0.0016X
	296.11500	0.11559	0.00808	0.00285	9.13770	-0.02865	0.06405	-0.31458	0.0	-0.01143
	306.45000	0.09463	0.00852	0.00143	9.44286	-0.02314	0.08717	0.51367	0.01827	-0.040.0
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83,4000 14,27555 14,27555 466.02342 2271.1795 2747.33917 9,10047 3,4099 10.0047 11,73395 11,63895 11,63895 11,63892 2707.1795 2747.33917 9,10047 3,4099 11,700000 11,63427 468.02342 2707.17955 2747.33917 9,10047 4,4774 4,4774 11,00710 4,68.02342 4,572.3464 4195.17397 2,4774 419762 3,464 4195.1739 11,00710 4,68.02342 4,4774 419762 3,464 4195.1739 11,00710 4,4700 11,7331 11,00710 4,68.02342 4497.1752 41,7460 10,7733 11,00710 4,68.02342 11,779	83,40600 14,2755 17,2755 46,050242 2271,1795 2747,33917 9 10047 1,0999 10047 14,0895 11,14959 12,04136 46,02342 2771,170000 11,04136 12,04136 46,02342 2771,770000 11,04136 12,04136 46,02342 2771,770000 11,04136 12,04136 46,02342 2471,770000 11,04136 12,04136 46,02342 2471,770000 11,04136 12	63.40000 117.00000 33.80000 55.60000 67.74500 85.23500 02.72500 20.21500 55.91000	14.27555 13.45845 12.64136	15.90000	468.02342	1488 61000	1752.26986	15.49151	-0.19946	0.13084
00.0000 13.45345 13.45845 46.02342 2707.17955 2747.33817 9.60047 3.46998 17.00000 12.44346 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.45136 13.4514 13.4512 13.4514	00.0000 13.45545 13.45545 46.02242 2707.17792 2747.33817 9.60047 3.46979 17.70000 12.45145 12.464156 12.46416 12.464156 12.464	.00.20000 .17.00000 .17.00000 .17.00000 .00.0000 .00.0000 .00.00000 .00.00	12.64136	14.27555	468.02342	2253.28118	2301.37394	11.73392	2.54163	0.17185
11.6000 11.64136 12.64136 468.02342 3161.07792 3195.53744 8.42192 4.21944 31.60000 11.00718 10.0718 468.02342 3614.97629 3645.14739 7.37693 4.44739 6.56000 11.00718 468.02342 468.6 4095.70347 6.5663 4.44739 6.7.74500 11.00718 468.02342 468.6 4095.70347 6.5663 4.44739 6.7.74500 11.00718 468.02342 4094.63471 468.02342 4094.63471 468.02342 4094.63471 468.02342 4094.63471 468.02342 4094.63471 468.02342 4094.63471 468.02342 4094.63471 468.02342 4094.63471 6.56000 1.00718 468.02342 6900.36490 6.00938 468.02342 6900.36490 691.00780 1.0	17.0000 11.64136 468.02342 3161.07792 3165.5774 8.42192 4.21944 31.80000 11.00718 11.00718 668.0746 4975 3645.14739 7.37693 4.44734 35.00000 11.00718 11.00718 668.0746 4975 5645.14739 7.37693 4.44556 35.74500 10.1731 10.1731 468.02342 5456.4747 556.4714 5.3456 3.69010 35.74500 10.1731 10.1731 468.02342 5475.1476 5747 5.5615 4.44556 35.74500 10.1731	33,80000 50,6000 67,74500 67,74500 02,72500 36,91000 57,91000	12.64136	13.45845	468.02342	2707.17955	2747.33817	9.80847	3.64998	0.20515
33.0000 11.02427 11.02427 469.02342 3314,97629 365 14739 7 737693 4.44734 6.50000 11.01731 10.1731 10.0000 11.01731 10.0	33.4.0000 11,02427 11,02427 466,02342 314,97629 3464,14739 713769 4,44734 9,44500 11,00016 11,00076 4,00073 4,00073 4,00073 11,00076 4,00073 4	50.6000 67.74500 65.23500 02.72500 20.21500 36.91000		12.64136	468.02342	3161.07792	3195.53744	8.42192	4.21944	0.23862
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10.17331 466.02342 4552.09415 5.89596 4.22735 19.3226 9.32266 9.32266 466.02342 5.09415 6.89518 4.89506 3.32266 19.3226 6.02342 5.09415 6.89518 4.89405 3.12356 6.89518 6.89518 4.89401.05573 4.49710 3.12356 6.103506 6.03506 466.02342 6400.77722 6417.69560 4.18201 2.6273 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.89518 6.99518	10.17331 468.02342 6452.09414 55.59596 4.27735 9.32264 9.32266 468.02342 5004.63477 5026.47144 5.34265 3.50796 9.32266 9.32262 646.02342 5407.17754 5792 5792 9.32264 9.32265 9.32264 648.02342 5407.177782 6417.86550 9.32564 5.32596 5.00306 6.00349 648.02342 5407.177782 6417.86550 9.32564 5.32596 5.00306 6.00349 648.02342 5407.177782 6417.86550 9.32564 5.32996 5.00306 648.02342 5407.177782 6417.86550 9.00494 9.18261 2.11822 6.00309 648.02342 5407.17782 6417.86560 9.00494 9.18264 5.00506 6.00349 680.02342 5407.17782 6417.86560 9.00494 9.18264 5.00506 649.02342 6407.17782 6417.86560 9.00494 9.00009 9.00	67.74500 85.23500 02.72500 20.21500 36.91000	11.00718	11.00718	468.02342	4068.87466	4095.70347	6.56163	4.44556	0.30583
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02,27500 8,47201 4,47201 468,02342 549,771,17540 4,4720 3,153796 6,021550 6,60373 7,62136 468,02342 549,716.02 5966,09573 4,47700 3,12256 5,03100 6,00378 6,00978 468,02342 549,71752 6417,66560 7,10201 2,62737 55,21000 6,00366 468,02342 5425,72752 6417,66560 7,10201 2,62737 55,21000 6,00366 468,02342 7629,2727 2,10256 1,10306 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 3,10360 001,6470 0,10570 6,45000 2,8900 468,02342 8679,5255 829,21006 3,13670 0,13570 6,45000 5,20000 468,02342 8645,6320 8658,34187 3,09861 2,10139 6,00000 5,20000 5,2000 468,02342 8645,6320 8658,34187 3,09861 2,10139	20.21500	02.72500 20.21500 36.91000 52.81000	9.32266	9.32266	468.02342	5004.63477	5026.47144	5.34265	3.98001	0.37533
20.21500 7.62136 6.69.73 46.80.2342 5940.71502 6477.6650 4.18201 2.6773 6.5000 6.80938	20,21500 7,62136 468,02342 5499,71602 544,78650 4,18201 2,647782 540100 6,80938 6,8093	20.21500 36.91000 52.81000	8,47201	8.47201	468.02342	5477.17540	5497.13528	4.88405	3.58796	0.41048
55.91000 6.09093 6.00934 668.02342 6490.77752 6417.86560 4.18201 2.162737 22.31000 6.03660 6.03660 6.03660 6.03660 6.03660 2.03660 6.0	36.2100 6.0360 6.0360 6.0366 6.0356 46.02342 640.77756 3.1994 2.11622 2.31000 6.0360 6.6471 6.0360 6	36.91000	7.62136	7.62136	468.02342	5949.71602	5968.09573	4.49780	3.12356	0.44565
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35,71000 5,7274, 5,724, 468,02342, 7253,94229, 7255,01256, 3,506956, 1,57418, 35,57000 4,18400 4,18400 4,18400 4,18400 4,18400 4,18400 4,18400 6,18400 0,18400	66.71000 5.68274 5.8827 46.02342 7245.01558 3.60556 1.15748 6.8.71000 5.68274 5.86274 6.15748 3.5079 0.64741 6.01248 0.15748 0		6.03606	6.03606	468.02342	6830.35991	6846.37586	3.91984	2.11622	0.51123
3.15600 4.1840 4.1840 468.02342 7649.94366 764.24712 3.50099 0.64741 95.11500 3.19233 3.19233 468.02342 8000.34640 8014.04206 3.54800 -0.15567 66.45900 2.89000 3.19233 468.02342 8279.58006 3.28534 -0.34534 14.15900 3.29500 468.02342 8645.68320 8658.34187 3.09661 2.10139 20.00000 5.20000 468.02342 8645.68320 8658.34187 3.09661 2.10139 3.09000 5.20000 468.02342 8645.68320 8658.34187 3.09661 2.10139	3.13500 4.1840 4.1840 468.02342 7649.9356 764.24712 3.50099 0.64741 95.11500 3.13233 3.12234 7.18234 680.02342 8000.36400 8014.04266 3.23630 -0.115547 66.45000 2.89000 468.02342 8679.59259 8292.81006 3.23534 -0.34534	68.71000	5.26274	5.26274	468.02342	7259.94229	7275.01258	3.68856	1.57418	0.54324
5.1500 5.1800 - 5.1853 468.0242 8000.3400 8014.0206 5.34800 - 0.15567 66.45000 2.89000 468.0242 8279.5955 822.81006 3.23534 -0.33534 14.15000 4.43000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.0000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.0000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.0000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.0000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.0000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.0000 5.20000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.00000 5.20000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.00000 5.20000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.00000 5.20000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.00000 5.20000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.00000 5.20000 5.20000 468.02342 8645.68320 8659.34187 5.09861 2.10139 20.00000 5.20000 5.20000 5.20000 5.20000 669.34187 5.09861 2.10139 20.00000 5.20000 669.34187 5.09861 5.10139 20.00000 5.20000 669.34187 5.09861 5.10139 20.00000 5.20000 669.34187 5.09861 5.10139 20.00000 5.20000 669.34187 5.09861 5.10139 20.00000 5.20000 669.34187 5.09861 5.10139 20.00000 5.20000 669.34187 5.00000 5.20000 669.34187 5.00000 5.20000 669.34187 5.00000 5.20000 669.34187 5.00000 5.20000 669.34187 5.00000 5.20000 669.34187 5.00000 5.20000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.000000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.0000000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.0000000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.34187 5.00000 669.3418 5.000000 669.3418 5.00000000 669.3418 5.000000 669.3418 5.000000 669.3418 5.000000 669.3418 5.000000 669.3418 5.000000 669.3418 5.000000 669.3418 5.000000	5.1500 5.1800 6.18553 468.02345 8000.36408 8014.06206 5.34800 -0.15567 66.45000 2.89000 6.45000 67795958 8225.81006 3.23534 -0.33534 14.15000 6.45000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 468.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 468.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.02342 8645.68320 8659.34187 5.09661 2.10139 20.00000 5.20000 6.00000 6.000000 6.000000 6.000000 6.000000 6.0000000 6.000000 6.000000 6.000000 6.000000 6.000000 6.000000 6.0000000 6.000000 6.000000 6.000000 6.000000 6.000000 6.000000 6.0000000 6.000000 6.000000 6.0000000 6.000000 6.0000000 6.0000000 6.0000000 6.0000000 6.0000000 6.0000000 6.0000000 6.00000000	83.14500	4.14840	4.14840	468.02342	7649.94366	7664.24712	3.50099	0.64741	0.57230
06.455000 2.89000 468.02342 8279.59258 820.61006 3.23534 -0.34534 14.15000 4.45000 468.02342 8645.68320 8659.34187 3.13620 1.27380 20.00000 5.20000 468.02342 8645.68320 8659.34187 3.09861 2.10139	14.15000 2.89000 468.02342 8279.59258 822.61006 3.23534 -0.35534 -	96.11500	3.19233	3.19233	468.02342	8000.36400	8014.04206	3.34800	-0.15567	0.59842
14.15000	14.15000	06.45000	2.89000	2.89000	468.02342	8279.59255	8292.81006	3.23534	-0.34534	0.61924
20.00000 5.20000 468.02342 8645.68320 8658.34187 3.09861 2.10139	20.00000 5.20000 468.02342 8645.68320 8658.34187 3.09861 2.10139	14.15000	4.43000	4,43000	968.02342.	.8487.62930.	8500.52334	3.15620	1.27380.	.0.63475
		20.00000	5.20000	5.20000	468.02342	8645.68320	8658.34187	3.09861	2.10139	0.64653
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	0.04265	-0.19433	-0.31780	0.20035 0.32001	
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117.00000	0.12353	-0.59983	-0.71296	0.17523	
150.60000	0.12/88	-0.64399	-0.64607	-0.13980	
167.74500	0.11694	-0.62318.	-0.56599	, -0.31638	many record the second tentant manages record from wanted
202 72500	0.10502	-0.56974	-0.45975	-0.47719	
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252.81000	-0.00419	-0.02128	0.09481	-0.44739	•
268.71000	-0.0404/	0.16565	0.244/5	-0.21509	
296.11500	-0.10802	0.59156	0.50845	0.36215	
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320.00000	-0.15381	0.87562	0.68303	0.80485 0.95027	
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15.00000	0.00165	-0.00750	-0.01336	0.00793	
41.25000	0.00158	-0.00724	-0.01060	0.00697	
62.50000	0.00133	-0.00637	-0.00765	86200.0	
63.40000	0.00100	-0.00512	-0.00430	-0.00192	
117.00000	0.00039	-0.00265	0.00012	-0.00816	
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202.72500	-0.00136	0.00637	C.00767	-0.00508	
220.21500	-0.00169	0.00854	0.00839	-0.00009	
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268.71000	-0.00239	0.01401	0.00930	120110.U	**
283.14500	-0.00249	0.01507	0.00963	0.02156	
296.11500	-0.00253	0.01563	79600.0	0.02392	
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0.03474	61.000	elected annual electron description particular variables	-	0.03500	000.49
0.03971	8.960			0.03971	8.960
0.04650	11.040			0.04650	11.040
0.04354	36.660			0.04354	36.660
0.03381	12.340			0.03381	12.340
0.06848	2.000			0.06848	2.000
0.05861	8.000			0.05861	8.000
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0.0	LB.SEC-SQ/INSQ IN.	BLADE EDGEWISE SECOND MOMENT OF AREA-IN.4TH	DELTA R IN.	BLADE FLATWISE SECOND MOMENT OF AREA-IN.4TH	DELTA R IN.
0.00744	15.00000	0.88587E+02	17.50000	0.87885E+02	17.50000
	17.50000	0.37941E+03	17.50000	0.93696E+02	17.50000
0.00423	17.50000	0.46903E+03	25.00000	0.27593E+02	25.0000
0.00168	25.00000	0.71842E+03	16.80000	0.23430E+02	16.80000
0.00149	16.80000	0.85000E+03	16.80000	0.234306+02	16.80000
0.00130	16.60000	0.000000103	16.60000	0.23430E+02	16.80000
0.00137	16.80000	0.85000E+03	16.80000	0.23430E+02	16.80000
0.00137	16.80000	0.90000E+03	17.49000	0.27065E+02	17.49000
0.00145	17.49000	0.90000E+03	17.49000	0.27430E+02	17.49000
95100.0	17,49000	0.84979E+03	17.49000	0.27272E+02	17,49000
0.00150	17.49000	0.73953E+03	17.49000	0.27190E+02	17.49000
0.00162	17.49000	0.64334E+03	15.90000	0.27116E+02	15.90000
0.00190	15.90000	0.59000E+03	15.90000	0.26950E+02	15.90000
0.00190	15,90000	0.56444E+03	15.90000	0.25433E+02	15.90000
0.00186	15.90000	0.53000E+03	12.97000	0.22950E+02	12.97000
0.00176	12.97000	0.53000E+03	12.97000	0.22950E+02	12.97000
0.00343	12.97000	0.53000E+03	7.70000	0.22950E+02	7.70000
0.00293	7.70000	0.53000E+03	7,70000	0.22950E+02	7.70000
0.00139	7.70000	0.53000E+03	4.00000	0.22950E+02	4.0000
BLADE	BLADE RIGID BODY PROPERTIES	TIES			
FLAPPING MASS	. 660383	LB SEC-SO/IN	NTA		
1ST MOM ABOUT HINGE FLAPPING INERTIA	11 11	81 81	-54		,
LAG FREQUENCY		CYCLES/REV	T		
BLA	BLADE MODAL PROPERTIES	ES	•		
BENDING MODE GENERALIZED MASSES	ERALIZED MASSES	ORGANISTICAL DE LA PROPERTIE DE L'ANGESTICAL DE L'ANGESTICAL DE L'ANGESTICAL DE L'ANGESTICAL DE L'ANGESTICAL DE		andrich erst betrückenders erständingen erständig i sesandande seis i den	
MODE(1)	= .125382	LB SEC-SQ/IN			*
HODE(2)	= .209446	LB SEC-SQ/IN		A second section desired section section washing a	*****
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	rkeseniNuurDegreesorFreedom(NP)	ADDITIONAL NO. DEGREES-OF-FREEDOM (NA) = 3	JOTAL_ NO. OFDEGREES-OF-FREEDOM. (NP+NA)# 25	ORDER OF MATRIX TO BE ADDED (NL) = 9	ORDER D.O.E. DE ADDED HATRIX INL-NA1. = 6	C. Selection (g.	مساعبية المرافع والمتمار والمت	VERTICAL_BIEILAR_PARAHETERS	IL NO. OF BIFILARS (N) = 4.00000	BIFILAR MASS (H) = .608000D-01	DISTANCE FROM C.R. (R) = 18,5000	BIFILAR FREQUENCY (W) = 4.00000	R1=R/(H#H-1 1, 1.23333	1 : 1.52111		1)**2 = 389,404	(R+R1 L	M*N*(R+R1)**2 = 94,7032	M*N*R1*(R+R1) = 5.91895	the same was the same that the	PRESENT ND. OF DEGRES-DE-FOREDAY (ND) = 06	1	(WILL)	•	ORDER OF MATRIX TO BE ADDED (NL) = 9	ORDERD.O.E.OF.ADDED_HATRIX(NL=NA)_=_6
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.601D-02, IHZH=131D-04, DXHUB=770526D-02, IHZH=131D-04, DXHUB=749371D-02, IHZH=128D-04, DXHUB=749251D-02, IHZH=128D-04, DXHUB=361312D-02, IHZH=291D-05, DXHUB=361374D-02, IHZH=394D-05, DXHUB=459374D-02, IHZH=932D-05, DXHUB=464374D-02, IHZH=932D-05, DXHUB=464374D-02, IHZH=999D-95, DXHUB=464	
-02, G2= .3440-01, XHUB= .3330-02, YHUB= -02, G2= .2190-01, XHUB= .1090-02, YHUB= -01, G2= .2130-02, XHUB= .2470-03, YHUB= -01, G2= .2130-02, XHUB= .2470-03, YHUB= -03, G2= .4190-02, XHUB= .1910-02, YHUB= -02, G2= .3100-03, XHUB= .1910-02, YHUB= -02, G2= .3090-02, XHUB= .1350-02, YHUB= -03, G2= .3090-02, XHUB= .1350-02, YHUB= -04, G2= .3090-02, XHUB= .1350-02, YHUB= -05, G2= .3090-02, XHUB= .1350-02, YHUB= -06, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= -07, G2= .3090-02, XHUB= .1350-02, YHUB= .14.3 .15.8 .11.6 .12.1 .1.1.6 .12.1 .1.1.6 .12.1 .1.1.6 .1.1.6 .1.1.1.6 .1.1.6 .1.1.1.1	- AMPLITUDE AND PHASE
NREVE 5, 61= ,4620-02, 62= ,3440-01, XHUB= ,3330-02, YHUB= ,88EV= 6, 61= ,1280-01, 62= ,2190-01, XHUB= ,3210-02, YHUB= ,88EV= 1,61= ,1280-01, 62= ,2190-01, XHUB= ,2210-02, YHUB= ,88EV= 10, 61= ,1280-01, 62= ,2130-02, XHUB= ,2210-03, YHUB= ,88EV= 10, 61= ,1240-01, 62= ,2130-02, XHUB= ,2470-03, YHUB= ,88EV= 10, 61= ,4540-03, 62= ,2130-02, XHUB= ,2470-03, YHUB= ,88EV= 12, 61= ,4540-03, 62= ,4180-02, XHUB= ,1910-02, YHUB= ,88EV= 13, 61= ,4540-02, 62= ,3100-03, XHUB= ,1910-02, YHUB= ,88EV= 13, 61= ,2520-02, 62= ,3100-03, XHUB= ,1910-02, YHUB= ,88EV= 15, 61= ,1930-02, 62= ,2900-02, XHUB= ,1350-02, YHUB= ,1740-02, YHUB= ,	OUTPUT
NREVE 5. 61 = .462D-02. 62 = NREVE 6. 61 = .124D-01. 62 = NREVE 1. 61 = .124D-01. 62 = NREVE 1. 61 = .453D-92. 62 = NREVE 1. 61 = .452D-02. 62 = NREVE 1. 61 = .452D-02. 62 = NREVE 1. 61 = .452D-02. 62 = NREVE 1. 61 = .179D-02. 62 = THE NUMBER OF REVOLUTIONS R INPUT FIXED SYSTEM MODES F E. 10	BIFILAR HARMONIC

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	d 6	.27.998D÷02. -132.76	.31304D-02 -18.104	32922D-02	324950±02 170.57	d 6	.937720-04 277080-03 292510-03 -71.303	.3672D-04 .30311D-04 .49135D-04 38.090	.68470D-04 36232D-05 68566D-04 -3.0290	_,22284D-05 ,80745D-05 -163.98	.86785D-05 33195D-05 .92217D-05	.218270-06 468590-06 .516940-06 -65.024
, many	6	.39280D-02. -100.26	.29031D-02 -31.080	.60291D+02	.23191D=02 124.83	d 89	.592090-03 214670-03 629810-03	.221870-03 223910-03 .315220-03 -45.263	.73182D-04 29406D-04 .78869D-04 -21.891	637360-05 425160-05 .766150-05 -146.29	.17703D-04 61179D-05 .18731D-04 -19.064	17881D-06 19328D-05 .19411D-05
	7 P	.515150÷02. -103.32	.41663D-02 -45.499	.67488D-02 79.690	.31602D-02 154.27	IN DEGREES 7 P	,235210-03 -,486850-03 ,540690-03 -64,214	.62830-04 165560-04 .650260-04	.16057D-03 29909D-04 .16333D-03 -10.552	-,18089D-04 -,43971D-05 -,18615D-04 -166.34	.20206D-04 75718D-05 .21578D-04 -20.543	.427910-06 101640-05 .110280-05 -67.169
	6 P	.29965D-02. -124.17	.33446D-02 30.184	13022D-01	.13860D=01 -166.74	PHASE ANGLE 6 P	.433620-03 884990-03 .985510-03 -63.896	.10481D=03 19251D-03 .21919D-03 -61.433	.36247D-03 10717D-03 .37798D-03 -16.471	-,402290-04 -,963350-05 -,413670-04 -166.53	.435430-04 174810-04 .469210-04 -21.874	.117950-05 234000-05 .262050-05 -63.248
1	5 P	18446D-01 29.256	37197D=01 -46.272	.21669D-01 -154.00	.35955D=01 139.47	RESPONSE AND 5 P	.111370-01 .199540-02 .113140-01	.988150-02 .164420-02 .100170-01 9.4468	.297090-02 .678280-02 .740490-02 66.346	.257080-03 651940-03 .700800-03 -68.479	.321430-03 .676860-03 .749300-03 64.598	.44537D-04 .33771D-04 .55893D-04 37.173
	4 4	.559910=01. -124.06	.36192D=01	347740-01	.47673D=01 167.95	AND TOTAL 4	.135130-01 13798 13864 -84.407		.49658D-02 65451D-02 .82157D-02 -52.813	.100880-02 270560-03 .10440-02 -15.013	.11809D-02 25992D-02 .28549D-02 -65.566	.292200-03 .177260-03 .341760-03 31.243
Lagranian	3 Р	9.7569	9.7675 -173.99	9.7962 -83.966	9,7978 6.2263	COSINE , SINE 3 P	10783D-02 .13435D-03 .10866D-02 .172.90	40974D-03 54539D-03 68215D-03 -126.92	-,20801D-03 -,10326D-03 -,23223D-03 -153.60	.20934D-04 17642D-05 .21008D-04	392900-04 774110-05 -400450-04 -168.85	.28154D-05 .17588D-06 .28209D-05 3.5747
And the second s	G 3	20305D-01. 53.478	_177.75	. 87900D_02 -66.614	.12959D-01 -31.531	Z P	71332D-03 .15737D-03 .73048D-03 167.56	17284D-03 11495D-03 .20757D-03	560-03 870-04 290-03 53	.183510-04 .355670-05 .186920-04 10.969	-,283000-04 -,190540-05 -,283540-04 -176,15	79781D-06 63593D-06 .10202D-05 -141.44
- Annual Control of the Control of t	I P	72570D-02. 52.592	.13026D-01 167.32	3 .3380ZD=02 -107.27	.12278D-01 5.5568	HARMONIC HUB OU	353870-03 .717840-04 .361080-03 168.53	.84053D-04 .12153D-03 .14776D-03 55.331	18544D-03124 20083D-04207 186 <u>53D-03 .126</u>	.116920-04 341450-05 .121810-04 -16.279	202460-04 .574400-06 .202540-04 178.37	.12641D-05 - .17520D-05 - .21604D-05 .54.189
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AND THE PERSON NAMED IN COLUMN TO TH	**************************************	Andre 1911; Andrews and 1920; Andrews Andrews	**************************************	. James write assess seems		A CONTRACTOR OF THE CONTRACTOR	ander onder demons there a	Annual States and the
	9.6	32567D-04 73596D-05 33389D-04	.113630±03 .543120-04 .125940-03 25.547	.12778D-03 .54140D-04 .13878D-03 22.962	9 B	40508D-04 .458880-05 .41041D-04 170.76	.99368D-04 21426D-03 .23618D-03 -65.120	.473710-04 .170700-03 .177150-03 74.490
	B 80	77459D-04 .72264D-05 .77795D-04	.10032D.03. 12696D-04 .10112D-03	.18752D-03 .33601D-04 .19054D-03 .10.218	8 E	99222D-04 .17450D-04 .10074D-03	.14243D-03 23445D-03 .27432D-03 -58.721	571370-05 -123360-03 -123500-03 92.652
And the second s	7 7	-,69643D-04 -,90956D-05 -,70234D=04	.252940_03 .87506D-04 .26765D-03 19.083	.29079D-03 .96591D-04 .30642D-03	7 B	90701D-04 16089D-04 92117D-04 169.94	.25702D-03 39836D-03 .47408D-03 -57.171	.82942D-04 .33292D-03 .34310D-03 76.010
POINT 1	6 P	13784D-0387238D-0513811D-03176.38	.553540.03 .153840-03 .574520-03 15.532	.62622D-03 .19182D-03 .65494D-03 17.031	POINT 2	185050-03 - .379130-04 .188890-03	.59969D-03 76927D-03 .97539D-03 -52.061	.15987D-03 .69282D-03 .71102D-03 77.007
ITAL_AMPLITUDEIN.GAND_PHASEANGLEIN.DEGREESOFPOINT	ro Gr	-,178000-03 - -,151420-02 - .152460-02 - -96,705	267980_02 .882830_02 .922600_02 106.89	38145D-02 .92417D-02 .99980D-02 .112.43	IN DEGREES OF	71084D-03 - 22860D-02 -23939D-02 -107.27	.96273D-02 .11193D-01 .14763D-01	12303D-01 .86053D-03 .12333D-01 176.00
HASE_ANGLE_]	4.	68218D-0216037D-0117428D-01113.04	.259740=01 .110330-01 .273940-01 &3.751	.13519D-01 - 51186D-02 14956D-01 -20.737	PHASE ANGLE 1	67874D-02 18411D-01 19622D-01 110.24	.609300-02 109630-01 .12543D-01 -60.936	.15241D-01 .28371D-01 .32206D-01 61.755
E IN G AND F	ъ м	.164950-03 - .453740-04 .121080-03	-,406680-03 ,385110-05 ,406680-03 179,46	56827D-03 10098D-03 -57717D-03 -169.92	IN G AND	.217540-03 - .373750-04 .220730-03	-,32357D-03 ,40307D-03 ,5168D-03	82776D-04 76443D-04 11267D-03
TAL AMPLITUD	er er	.10540D-03 .10159D-04 .10589D-03 5.5052	.236310-03 .233260-04 .237460-03	.39448B-03 .80199D-04 .40255D-03	TAL AMPLITUDE	.141410-03 .378640-05 .141460-03 1.5338	.275760-03 .166130-03 .321940-03	.16740D-03 - .15717D-03 - .24459D-03 -
COSINE,SINE,TO	<u>п</u>	.74646D-04 17197D-04 .76601D-04 -12.973	-,446410-03 - -,205510-03 - ,491450-03 - -155,28 -	21825D-03 - 27545D-04 - .21998D-03 - -172.81 -	COSINE, SINE, TO	.10408D-03 -,70780D-05 -,10432D-03 -3.8905	-, 794280-03 - -, 390160-03 ,884930-03	.117220-03 - .224430-04 - .119350-03 -

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а. Ф	29305D-04 .10721D-04 .31205D-04 159.90	10347D-03 11460D-03 15440D-03	527400-04 510790-04 .73421D-04 -44.083	HADDISTANCE OF THE STANDARD CONTRACT OF THE ST	G 6	.156870-04 .316780-03 .317170-03	147290-03 -,224180.03 .268240-03 -123.31	-,49814D-05 -,96211D-04 -,96340D-04 -92,964		Appear silles manage ; manage carrie	
æ	60697D-04 .19217D-04 .6366D-04 162.43	-,12237D-03 -,16250D-03 -,20342D-03 -126,98	. 876380-04 158480-04 . 890590-04 -10.250		ю. «О	-,99326D-04 .44778D-03 .45866D-03	21725D-03 61673D-04 .22584D-03 -164.15	.119820-03 121420-03 .170580-03	and the second of the second o	APPRILL SEASON SERVICE PROPERTY.	
۲	68260D-04 .23639D-04 .72237D-04 160.90	-,244300-03 -,210320-03 -,322360-03 -139,27	898780-04 .165620-03		7 P	399680-05 .565970-03 .565990-03	29150D-03 41105D-03 .50392D-03 -125.34	93473D-05 13732D-03 .13764D-03	ne na companya e a si sa colombia de la companya e a si sa colombia de la colombia della colombia de la colombia de la colombia della colombi	section tenence statute systems	
Ф	14680D-03. .52829D-04 .15602D-03	-,52364D-03 -,42657D-03 -,67540D-03 -140.83	. 32953D-03 - 16450D-03 . 36831D-03 -26.528	FPOINT 4	d 9	80049D-04 .10613D-02 .10643D-02	.61440B-03 .77273B-03 .99270B-03	24120D-04 18224D-03 .18383D-03 -97,539	edinosta i i casadonostas i i rayonostas de la casadonostas e la casadonosta de la cas	states majori trains	
ru Gr	89703D-03. 22399D-02 .24129D-02 -111.82	.74275D-02 75659D-02 .10602D-01 -45.529	.62943D-02 .62943D-02 .64687D-02 76.664	IN DEGREES OF	rų Gr	13883D-01 42247D-02 .14512D-01	.11071D-01 84907D-02 .13952D-01 -37.485	66885D-03 16426D-02 .17735D-02 -112.16	and the second s	Andrew Printers and Andrew	
4 . O	392690=02 .837310-02 .924820-02	11864D-02 72463D-02 - .73428D-02 - -99.298	16435D-01 13471D-02 _16490D-01 _175.31	PHASE ANGLE 1	д 7	19349b-01 70285b-02 .20586b-01 -160.04	28815D-01 214290-01 .35910D-01 -143.36	.79289D-0238277D-0288044D-0225.769	(0-1739)	.16588	LC.1740-1759)
m D	.22363D-03 .22363D-04 .13767D-03 9.3481	.60564D-03 - .49249D-03 - .78061D-03 - 39.117	.15678B_03 .31328D_04 .15988D_03 168.70	IN G AND	3 P	-,43829D-03 - -,21240D-04 - .43881D-03 - -177,23	.167100-03 - .167100-03 - .246470-03 - 42.687	12887D-04 .43586D-03 .43605D-03 91.694	17	349550-01	J
e.	.71563D-04 .71563D-05 .99510D-04	.21018D-03 24978D-04 -21166D-03	29805D-03 10535D-03 .31612D-03 -160.53	TAL AMPLITUDE	2 P	567790-03 151030-03 606880-03 4.410	.50814D-03 .53723D-03 .73999D-03	38248D-03 - 15571D-03 .41296D-03		*****	AR VELOCITIES
<u>п</u>	-, 39469D-05 -, 39469D-05 -, 63787D-04 -3, 5476	.22796D-03 .38921D-04 - .23126D-03	12023D-03 - 2980 73060D-04 - 1053 14069D-03 - 3161 31.285 - 160.5	COSINE, SINE, TOTAL	1 9	60456D-03 . 27274D-03 . .66323D-03 .	14888D-02 14651D-02 .20888D-02 -135.46	.422390-03 - .188820-03 - .462670-03		.34889D-0116560	INITIAL BIFILAR

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interest control in		.108350-02	.445700	and the same of the same of
tra dissi prodo depte ameni		29884D-03	-02	
100m		57780-02 39220-03	22056 921940-02	
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105950-04	1	.101090-03	. 1335590-01	
	43242D-	.196280-03 566270-02 519730-01	14798 :307640-01 14.582	-
.45858D-04	(LC.1774-1779) -01330850-02	.38650D-02 .38200D-03 .11073	1.2027 5.2717 5.2717	
59740-03	162990	VARIABLES DISPL.(LC.1780-1859) 52D-04 .47216D-04 .38550D-05 35D-05 .31296D-07 .38200D-057D-02 .31296D-01 .31073	-, 21021 -, 210130-04 -, 110130-04	
.35604D-(HUB VELOCITIES		- 117990-01 - 1334430-03 - 1.22740	
.150650-02	INITIAL HUB	.,41930D-04 .837 -,47164D-04 -,533 -,13830D-04 -,547	. 47650D-01 . 10169 - 7794450D-02	many iterate annual vendos

RESULTS	at mean
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						(0=NO,10R-1=YES)	PRINTOUT(0=NO,1=YES)	36	=		.=	=	•		Ë
SYSTEM MODES	1 ABSORBERS	rlars	ILARS	JF-FREEDOM	SNS	DN=0)	PRINTOUT(PRINTOUT	PRINTOUT	PRINTOUT	PRINTOUT	PRINTOUT	PRINTOUT	PRINTOUT	PRINTOUT
FIXED SYSTEP	FIXED SYSTEM ABSORBERS	INPLANE BIFILARS	NUMBER OF VERTICAL BIFILARS	TOTAL NO. OF DEGREES-OF-FREEDOM	OF A.C. STATIONS	ROTOR COUPLING SWITCH	ICES	FIXED SYSTEM MATRICES	MATRICES	ADD EIX.SYS, ABSORBER PRINTOUT	BIFILAR	ADD VERTICAL BIFILAR PRINTOUT	BIFILAR (9X9) PRINTOUT	FILAR (9X2)	
NUMBER OF 1	NUMBER OF F	NUMBER OF 1	NUMBER OF	TOTAL NO. C	NUMBER OF	ROTOR COUP	ROTOR MATRICES	FIXED SYSTE	ADD ROTOR	ADD FIX.SYS	ADD INPLANE	ADD VERTICA	INPLANE BI	YERTICAL BIEILAR (9X2) PRINTOUT	GANHAS

VERTICAL BIFILAR PARAMETERS	PARAMETERS	
BI		
BIFILAR HASS	= (E)	.6080000-01
DISTANCE FROM C.R.	£	18.5000
BIFILAR FREQUENCY	= (R)	4.00000
RIER/(N*H-1.)	H.	.1.23333
R1*R1	n	1.52111
RARI	n	19,7333
(R+R1)**2	n	389.404
MXNX(B4R) 1	N	4, 72915.
M*N*(R+R1)**2	n	94.7032
M*N*R1*(R+R1)	P	5,91895
	a prince annua annua annua	
PRESENT_NOQF_DEGREES_OF_FREEDOM(NP.)	RES-OF-FREEDO	H(NP.)
ADDITIONAL NO. DEGRE	DEGREES-OF-FREEDOM	0M (NA) = 3
ORDER OF HATRIX TO BE ADDED (NL) = 9	REES-OF-FREEDO BE ADDED	DM. (NP+NA), = 16
ORDER D.Q.E. OF ADDED HATRIX (NL-NA) =	ADDED NATRIX	(NL-NA) = 6
and with easier these capes these three parts into their three thr	; ! !	in some area was also area was the control area was inter-
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SINE COMPONENT SINE COMPONENT SINE COMPONENT	.500000	-170.00	500.000	.500000	-201.000	25.0000	120.000	350.000	
COSINE SINE APPLITUDE PHASE(DES) FIXED SYSTEM ABSORBER(S) FIXED SYSTEM ABSORBER(S) LIGATOR STATEMENT LIGATOR SYSTEM ABSORBER(S) LIGATOR SASSORD SASS			4	COMPONENT	***************************************	Address of the state of the sta	odienie i i mandonie i i de i de de de de de de de de de de de de de		angen de la companya de la companya de la companya de la companya de la companya de la companya de la companya
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casso ander casso were se			The second control of the second control of						A	, DYHUB=249	, DYHUB=330	, DYHUB=	, DYHUB=286	, DYHUB=368
2111						e description description of the second of			der der der der der der der der der der	.462D-05, DXHUB=863	XHUB=837	829	0XHUB= -1.01	.699D-05, DXHUB= -1.16
										.462D-05, D	.337D-05, DXHUB=837	.308D-05, D	.533D-05, DXHUB= -1.01	.699D-05, D
			***************************************							.2630-02, THZH=	.192D-02, THZH=		.350D-02, THZH=	.363D-02, THZH=
*			and the second second second								,	ł	1	
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			***************************************					30.000	111111 POPPE - 4		Į.	-{		į
			***************************************					FOR PSI =	water aming all us of the	.3270-01, XHUB=	.320D-01, XHUB=	.238D-01, XHUB=	.273D-01, XHUB=	.310D-01, XHUB=
-,47168D-02 ,44988D-03 ,68643D-03	11020D-01	-,2604cD-02	37338D-02	368240-02	333120-02	155210-02	466040-03	BIFILAR INITIAL DISP & VEL FOR PSI	.49550D-02 .17144D-03 41782D-02		.5130-02, G2= .3	.480D-03, 62= .2	2, 62=	.233D-02, G2= .3
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H= .475D-05,	H≃ .268D-05,	H= .421D-05,	H= .5670-05,	H= .452D-05,	H= .371D-05,	H= .459D-05,					7 P	.35755D-02 41.773	.26310D-02 98.182	.23000D-02 -173.77	.50300D-02
.161D-02, THZH=	.109D-02, THZH=	.230D-02, THZH=	.230D-02, THZH=	.160D-02, THZH=	.178D-02, THZH=	.227D-02, THZH=		21.1		41 1 1 MANAGEMENT 11 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Ф	.11213D-01 70.857	.10635D-01 76.653	.130260-01	165000-01
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= .161D-03,	152D-02,	.2660-02,	.1870-02,	1340-02,	.2170-02,	= .2720-02,	VERGE = 13	9.	***************************************	PHASE	4	10-0	. 236920-01 .7 -29.191 -55	. 22214D-01 .8 82.317 -14	7. 100-01782
11, XHUB≃	2, XHUB=	02, XHUB=	22, XHUB=	2, XHUB=	72, XHUB=	SHX	TO CON	13.8	30.2	AMPLITUDE AND PHASE		.27	. 23.	. 22.	.28
.172D-01,	.6050-02,	.5960-02,	.390D-02,	.1450-02,	.3140-02,	.108D-02,	REQUIREC	3	п	- AMPLIT	κ d	9.5710 87.610	9.5752 177.26	9.6299	9.6216
.743D-02, G2=	.607D-02, G2=	.601D-02, G2=	.2640-02, 62=	.3760-02, 62=	.1060-02, 62=	.1980-02, 62=	THE NUMBER OF REVOLUTIONS REQUIRED TO CONVERGE INDICES IN HZ	15.3 14.3	YCE FACTOR TO G	COUTPUT	с С	.12416D-01 52.740	.24610D-01 -127.52	.33980D-01 25.261	246920-01
7, 61=	8, 61=	9, 61= .6	10, 61=	NREV= 11, 61= .3	NREV= 12, G1= .1	NREV= 13, G1= .1	NUMBER OF	6.40	THE CONVERGENCE	BIFILAR HARMONIG	a.	.67049D-02 167.18	8	.111550-01 8.6491	K1459N-09
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565D-03 : 12637D-02 : 46626D-01 : 11667D-0176696D-0342565D-0323171D-0371377D-0116073D-0262218D-0324685D-036155D-036156D-031377D-0371377D-0116073D-0262218D-032468B-036155D-036155D-042636D-0116073D-011032D-022673D-031056D-031056D-0310798D-0310798D-0310798D-0310798D-036821D-042631D-022673D-022573D-031078D-031056D-032673D-042633D-042633D-042633D-042633D-04263D-04263D-04263D-04263D-04263D-04263D-04263D-052673D-032773D-031079BD-031079BD-031079BD-04263D-04260D-04263D-04263D-04260D-04260D-04263		1.5860	;	-40.327	-79.257	.76189	-167.74	162.58	3.1630	139.08
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1406-04 - 10.248 - 10.25.735 - 7.6898 - 141.67 - 146.09 - 110.50 - 10.248 - 10.25.735 - 7.6898 - 141.67 - 146.09 - 110.50 - 10.26.03		.45630D-04	.930180-04	374110-03	713770-01	16023D-02		28682D-03		14193
\$\text{6770-04} \tag{6.572010_04} \tag{6.561140_02} \tag{6.280690_02} \tag{6.28730_03} \tag{5.6770_03} 5.		4.3112 4.3112	6.7779	16.248	-55.735	-7.6898	300	-146.09	-110.50	-145.82
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490-05					-19.816	-73.326	175.73	170.79	-156.93	164.96
776B-0599350D-0639548D-02 .4277LD-0324576D-0410858D-0412090D-04 .9990-05 .86276D-05 .89678D-02 .6424LD-03 .25456D-04 .1092ID-04 .13549D-04 .9990-05 .86276D-05 .86276D-05 .39678D-03 .25466D-04 .1092ID-06 .23.856 -63.167 .87860D-05 .37223D-05 .13536D-03 .31970D-0460135D-0650591D-0623038D-05 .137860D-05 .373860D-05 .137380D-05 .124.49 .85.2491 .27.189 .25.16698.582 -102.60 -124.49 .124.49 .25.189 .25.166 .23.1900D-04 .12655D-04 .25113D-04 .25120D-05 .25628D-05 .25628D-05 .25587D-04 .23570D-04 .23570D-04		.45204D-05	.312400-05		.320590-03	.479320-03			.611590-05	=,27882
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372230-05 .372230-05 .123940-03 .319700-04601350-06505910-06230380-05 3150-05 .341970-06 .636660-04 .150210-04399490-052263310-05335380-05 3150-05 .373800-05 .132340-03 .353230-04 .403000-05 .2263310-05 .406890-05 364 5.2491 27.189 25.166 -98.582 -102.60 -124.49 AT 4 A/C LOCATIONS AMPLITUDE IN 6 AND PHASE ANGLE IN DEGREES OF POINT 1 2 p			inne man since amon		ļ	1	***************************************			-
1150-05		.469290-06	.14676D-05	.37223D-05	.123940-03	.319700-04	60135D-06	50591D-06	23038D-05	28873
AT 4 A/C LOCATIONS AT 4 A/C LOCATIONS AMPLITUDE IN G AND PHASE ANGLE IN DEGREES OF POINT 1 P		225270-06	196150-05	373800-05	139340-03	353230-04	.40300D-05	.23191D-05	.406890-05	14157
AT 4 A/C LOCATIONS AMPLITUDE IN 6 AND PHASE ANGLE IN DEGREES OF POINT 1 2 P 5 P 6 P 6 P 6 P 6 P 6 P 7 P 8 P 6 P 7 P 8 P 6 P 7 P 8 P 8 P 6 P 7 P 8 P 8 P 8 P 8 P 8 P 8 P 8 P 8 P 8		52.748	41.564	5.2491	27.189	25.166	-98.582	-102.60	1 1	-101.77
E,TOTAL AMPLITUDE IN G AND PHASE ANGLE IN DEGREES OF POINT 1				1			-	and the same of the same	interes arrest initiation	****
AMPLITUDE IN G AND PHASE ANGLE IN DEGREES OF POINT 1 2 P			AT A		S					
59704D-0490025D-0436910D-0217316D-04 .12665D-0425113D-04 .16651D-041545D-04 .23570D-04		SINE, SINE, T		9 Ni	PHASE	DEGREES	POINT	and a second control of the second		
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. 16851D-04 .91842D-04 .26162D-0110014D-02 .25028D-0515837D-04 .23570D-04 -			59704D-04	90025D-04		139960-02	.173160-04	.126650-04	251130-04	
		:	16851D-04	.91842D-04		100140-02	.25028D-05	158370-04	.235700-04	
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we virging the second	.54919D-04 94960D-04 .10970D-03	65015D-04 51631D-04 .83022D-04 -38.454	AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA	ō.	.57362D-05 62740D-05 .85010D-05	.14387D-04 19107D-03 .19161D-03 -85.694	.788820-04 .314370-04 .849150-04 21.729		Ф 6	14351D-06 .15954D-04 .15955D-04	10098D-03 35946D-05 .10104D-03	.440760-04
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Appendix D. Details of Coupled Rotor/Bifilar/Airframe Analysis TABLE OF CONTENTS

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D.1 Inplane Bifilar Equations of Motion

The inplane bifilar rotor head absorber is a single degree-of-freedom system. It can be represented as a one degree-of-freedom pendulum as shown in Figure D.1-1. The rotating coordinate system shown here is located on the main rotor hub. The equivalent pendulum arm, r, and the distance from the center of rotation, R, are related by equation (1) (see Figure D.1-2), often referred to as tuning equation. The location of the c.g. relative to the inertia frame system is given by equation (2) shown in Figure D.1-2. Substituting equation (2) into the Lagrange's equations, the non-linear equations of motion are derived, equations (3)-(6), and shown in Figure D.1-3.

To obtain the linear set of equations of motion, equations (7)-(10) (see Figure D.1-4), small angle assumptions were made, e.g. $\sin\gamma_k \sim \gamma k$, and $\cos\gamma_k \sim 1$. Also, the second order terms were neglected. For identical bifilars, further simplification of these equations can be made by transferring the rotating bifilar coordinate, γ_k , into the fixed system coordinates. The equation for the coordinate transformation used in shown in Figure D.1-5, equation (11). Thus the transformed equations of motion are derived, equations (12)-(17) shown in Figure D.1-5.

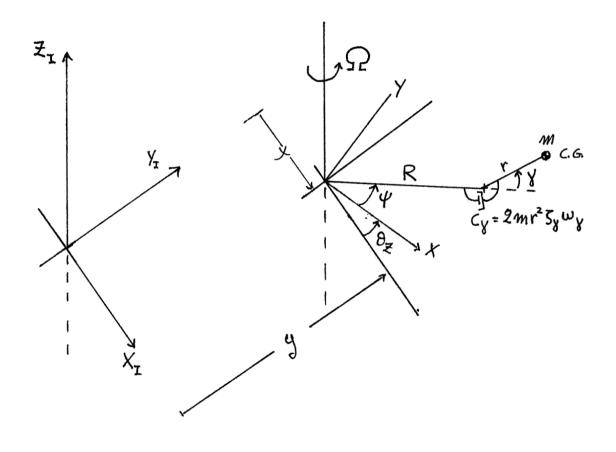


FIGURE D.1-1: INPLANE BIFILAR MATH MODEL

$$\eta = \sqrt{\frac{R}{r}} \left(\text{TUNING} \sim \text{PER REV} \right)$$
(1)

$$\{\chi_{x}\} = \{\chi\} + \left[\Theta_{z}\right] \cdot \left[\Psi\right] \cdot \left\{R\{V_{i}\} + r\left[\Gamma\right] \cdot \left\{V_{i}\right\}\right\} \tag{2}$$

WHERE:

$$\begin{bmatrix} \Theta_{\mathbf{z}} \end{bmatrix} = \begin{bmatrix} \cos \theta_{\mathbf{z}} & -\sin \theta_{\mathbf{z}} & 0 \\ \sin \theta_{\mathbf{z}} & \cos \theta_{\mathbf{z}} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\left\{ \bigvee_{i} \right\} = \left\{ \begin{array}{c} 1 \\ 0 \\ 0 \end{array} \right\}$$

FIGURE D.1-2: POSITION VECTOR FOR INPLANE BIFILAR MASS

X- EQUATION

$$(m_{e} + M_{T})\ddot{x} + 2m_{e}\omega_{x} \mathcal{T}_{x}\dot{x} + m_{e}\omega_{x}^{2} \times$$

$$+\sum_{k=1}^{N}m_{k}\left\{-\left[r_{k}\sin(\psi_{k}+\theta_{z}+\gamma_{k})+R_{k}\sin(\psi_{k}+\theta_{z})\right]\theta_{z}^{"}-\left[r_{k}\sin(\psi_{k}+\theta_{z}+\gamma_{k})\right]\eta_{k}^{"}\right\}$$

$$-2\Omega \left[r_{k}\cos(\psi_{k}+\varrho_{+}\gamma_{k})\right]\dot{\gamma}_{k} - \left[r_{k}\cos(\psi_{k}+\varrho_{z}+\gamma_{k})\right]\dot{\gamma}_{k}^{2}$$

$$-2\left[r_{k}\cos(\psi_{k}+\partial_{z}+y_{k})\right]\dot{\theta}_{z}\dot{y}_{k}-2G_{2}\left[r_{k}\cos(\psi_{k}+\partial_{z}+y_{k})+R_{k}\cos(\psi_{k}+\partial_{z})\right]\dot{\theta}_{z}$$

$$-\left[I_{k}\cos(\psi_{k}+\partial_{z}+y_{k})+R_{k}\cos(\psi_{k}+\partial_{z})\right]\partial_{z}^{2}$$

$$-\Omega^{2}\left[r_{k}\cos\left(y_{k}+\theta_{z}+y_{k}\right)+R_{k}\cos\left(y_{k}+\theta_{z}\right)\right]\right\}=F_{x} \qquad (3)$$

FIGURE D.1-3: NON-LINEAR EQUATIONS OF MOTION FOR INPLANE BIFILAR

$$(m_{\epsilon}+M_{\tau})\ddot{y} + 2m_{\epsilon}\omega_{y}S_{y}\dot{y} + m_{\epsilon}\omega_{y}^{2}\dot{y}$$

$$+\sum_{k=1}^{N} m_{k} \left\{ \left[r_{k} \cos \left(\psi_{k} + \theta_{2} + \gamma_{k} \right) + R_{k} \cos \left(\psi_{k} + \theta_{2} \right) \right] \dot{\theta}_{2} + \left[r_{k} \cos \left(\psi_{k} + \theta_{2} + \gamma_{k} \right) \right] \dot{\gamma}_{k} \right\}$$

$$-2\Omega \left[r_{k} \sin \left(y_{k} + \theta_{2} + y_{k} \right) \dot{y}_{k} - \left[r_{k} \sin \left(y_{k} + \theta_{2} + y_{k} \right) \right] \dot{y}_{k}^{2}$$

$$-2\left[r_{k}Sm\left(\psi_{k}+\theta_{z}+\gamma_{k}\right)\right]\dot{\theta}_{z}\dot{\gamma}-2\Omega\left[r_{k}Sm\left(\psi_{k}+\theta_{z}+\gamma_{k}\right)+R_{k}Sm\left(\psi_{k}+\theta_{z}\right)\dot{\theta}_{z}\right]$$

$$-\left[r_{k}\sin(\psi_{k}+\partial_{z}+\dot{\gamma}_{k})+R_{k}\sin(\psi_{k}+\theta_{z})\right]\dot{\theta}_{z}^{2}$$

$$-\Omega^{2}\left[r_{k}\sin(\psi_{k}+\theta_{2}+y_{k})+R\sin(\psi_{k}+\theta_{2})\right]\right\} = F_{y} \qquad (4)$$

FIGURE D.1-3: NON-LINEAR EQUATIONS OF MOTION FOR INPLANE BIFILAR (CONTINUED)

$$\left\{ m_{G} + \left[\sum_{k=1}^{N} m_{k} (r_{k} + R_{k} + 2r_{k} R_{k} \cos \gamma_{k}) \right] \right\} \hat{\theta}_{z}$$

$$+2m_{e}w_{oz}S_{oz}\dot{\vartheta}_{z}+m_{e}w_{oz}^{2}\vartheta_{z}$$

$$+\sum_{k=1}^{N}m_{k}\left\{-\left[r_{k}Sm(\psi_{k}+\partial_{z}+\gamma_{k})+R_{k}Sm(\psi_{k}+\partial_{z})\right]^{\frac{1}{N}}\right\}$$

$$+\left[r_{k}\sin\gamma_{k}\left(2r_{k}\sin\gamma_{k}+R_{k}\right)\right]\gamma_{k}^{2}=M_{Z} \tag{5}$$

FIGURE D.1-3: NON-LINEAR EQUATIONS OF MOTION FOR INPLANE BIFILAR (CONTINUED)

$$m_{\kappa} r_{\kappa} \left\{ -\left[\sin(\psi_{k} + \theta_{z} + \gamma_{\kappa}) \right] \ddot{x} + \left[\cos(\psi_{k} + \theta_{z} + \gamma_{\kappa}) \right] \ddot{y} \right.$$

$$+ \left[r_{\kappa} + R_{\kappa} \cos \gamma_{\kappa} \right] \ddot{\theta}_{z} + r_{\kappa} \dot{\gamma}_{\kappa} + \left[2 r_{\kappa} \delta_{\kappa} \omega_{y_{\kappa}} \right] \dot{\gamma}_{\kappa}$$

$$+ \left[2 \Omega R_{\kappa} \sin \gamma_{\kappa} \right] \dot{\theta}_{z} + \left[R_{\kappa} \sin \gamma_{\kappa} \right] \dot{\theta}_{z}^{2}$$

$$+ R_{\kappa} \Omega^{2} \sin \gamma_{\kappa} \right\} = 0.0 \qquad (6)$$

$$(m_{G} + M_{T})\ddot{X} + 2m_{G} w_{X} \ddot{S}_{X} \dot{X} + m_{G} w_{X}^{2} \dot{X}$$

$$+ \sum_{k=1}^{N} m_{k} \left\{ -\left[(r_{k} + R_{k}) S_{1} m \psi_{k} \right] \ddot{\theta}_{Z}^{2} - \left[r_{k} S_{1} m \psi_{k} \right] \ddot{y}_{k} \right\}$$

$$- \left[2\Omega (r_{k} + R_{k}) cos \psi_{k} \right] \dot{\theta}_{Z} - \left[2\Omega r_{k} cos \psi_{k} \right] \dot{y}_{k}$$

$$- \Omega^{2} \left[(r_{k} + R_{k}) cos \psi_{k} - r_{k} \dot{y}_{k} S_{1} m \psi_{k} - (r_{k} + R_{k}) \partial_{Z} S_{1} m \psi_{k} \right] \right\} = F_{X}$$

$$(7)$$

FIGURE D.1-4: LINEAR EQUATIONS OF MOTION FOR INPLANE BIFILAR

$$(m_{\varepsilon}+M_{\tau})\ddot{y} + 2m_{\varepsilon}w_{\gamma} \ddot{y} \dot{y} + m_{\varepsilon}w_{\gamma}^{2} \dot{y}$$

$$+ \sum_{k=1}^{N} m_{k} \left\{ \left[\left(r_{k} + R_{k} \right) \cos \psi_{k} \right] \ddot{\theta}_{z}^{2} + \left[r_{k} \cos \psi_{k} \right] \ddot{y}_{k} \right\}$$

$$- \left[2\Omega \left(r_{k} + R_{k} \right) \sin \psi_{k} \right] \dot{\theta}_{z}^{2} - \left[2\Omega r_{k} \sin \psi_{k} \right] \dot{y}_{k}$$

$$- \Omega^{2} \left[\left(r_{k} + R_{k} \right) \sin \psi_{k} + r_{k} \dot{y}_{k} \cos \psi_{k} + \left(r_{k} + R_{k} \right) \dot{\theta}_{z} \cos \psi_{k} \right] \right\} = F_{y}$$

(8)

$$\left\{ M_{G} + \left[\sum_{k=1}^{N} M_{k} (v_{k} + R_{k})^{2} \right] \right\} \tilde{Q}_{Z}$$

$$+\sum_{k=1}^{N}m_{k}\left\{-\left[\left(r_{k}+R_{k}\right)Siny_{k}\right]\ddot{X}+\left[\left(r_{k}+R_{k}\right)cosy_{k}\right]\ddot{Y}\right\}$$

$$+\left[r_{k}\left(r_{k}+R_{k}\right)\right]\ddot{\gamma}_{k}\right\} = M_{\partial z} \tag{9}$$

$$m_k r_k \{ [-sin \psi_k] \ddot{x} + [cos \psi_k] \ddot{y}$$

$$+ [r_{k} + R_{k}] \frac{\partial}{\partial z} + r_{k} \frac{\partial}{\partial k} + r_{k} \frac{\partial}{\partial k} + r_{k} \frac{\partial}{\partial z} \frac{\partial}{\partial z} \frac{\partial}{\partial k} + r_{k} \frac{\partial}{\partial z} \frac{\partial}{\partial z} \frac{\partial}{\partial z} + r_{k} \frac{\partial}{\partial z} \frac{\partial}{\partial z} \frac{\partial}{\partial z} \frac{\partial}{\partial z} \frac{\partial}{\partial z} + r_{k} \frac{\partial}{\partial z}$$

FIGURE D.1-4: LINEAR EQUATIONS OF MOTION FOR INPLANE BIFILAR (CONCLUDED)

$$y = \frac{1}{N} \gamma_0 + \frac{2}{N} \gamma_5 \sin \psi + \frac{2}{N} \gamma_c \cos \psi \qquad (11)$$

$$(m_{\epsilon} + M_{\tau}) \ddot{x} + (2m_{\epsilon} \omega_{x} 5_{x}) \dot{x} + (m_{\epsilon} \omega_{x}^{2}) x - m r \dot{y}_{5} = F_{x}$$
 (12)

Y-EQUATION

$$(m_{e} + M_{\tau})\ddot{y} + (2m_{e}w_{y}S_{y})\dot{y} + (m_{e}w_{y}^{2})y + m_{f}\ddot{y}_{c} = F_{y}$$
 (13)

$$[m_{e} + M_{T}(r+R)^{2}] \ddot{\theta}_{z} + (2m_{e} \omega_{z} 5_{\theta_{z}}) \dot{\theta}_{z} + (m_{e} \omega_{\theta_{z}}^{2}) \dot{\theta}_{z} + [m(r+R)r] \ddot{\gamma}_{o} = M_{z}$$
(14)

FIGURE D.1-5: INPLANE BIFILAR EQUATIONS IN FIXED SYSTEM COORDINATES

$$N(1 + \frac{R}{r}) \frac{\ddot{\theta}}{2} + \ddot{\gamma}_{o} + \frac{R}{r} \Omega^{2} \dot{\gamma}_{o} + 25 \omega_{s} \dot{\gamma}_{o} = 0$$
 (15)

$$\left(-\frac{N}{2r}\right)\ddot{x} + \chi_{5} + 25 \omega_{5} \chi_{5} - 2\Omega \dot{\chi}_{c} + \Omega \dot{\chi}_{c}^{2} (R-1) - 25 \omega_{5} \Omega \dot{\chi}_{c} = 0$$
(16)

$$\left(\frac{N}{2r}\right)\ddot{y} + \ddot{y}_{c} + 25 \omega_{s}\dot{y}_{c} + 2\Omega\dot{y}_{s} + \Omega^{2}\left(\frac{R}{r}-1\right)\chi_{c} + 25\omega_{s}\Omega\chi_{s} = 0$$
(17)

FIGURE D.1-5 INPLANE BIFILAR EQUATIONS IN FIXED SYSTEM COORDINATES (CONCLUDED)

D.2 Vertical Bifilar Equations of Motion

The vertical bifilar rotor head absorber is a single degree of freedom system. The math model is presented in Figure D.2-1. The equivalent pendulum arm, r, and the distance from the center of rotation, R, are related by the tuning equation (18), shown in Figure D.2-2. The vector location of the dynamic mass (c.g.) is given by equation (19), shown in Figure D.2-2. Substituting equation (19) into the Lagrange's equation, also assuming small motions and neglecting second order terms, the linear set of equations of motion with six hub degrees-of-freedom are derived. They are shown in Figure D.2-3, equations (20)-(26).

For identical vertical bifilars, further simplification of these equations can be made by transferring the rotating coordinate, β_k , into the fixed system coordinates. The equation for the coordinate transformation used is shown in Figure D.2-4, equation (27). Thus the transformed equations of motions are derived, equations (28)-(36), shown in Figure D.2-4.

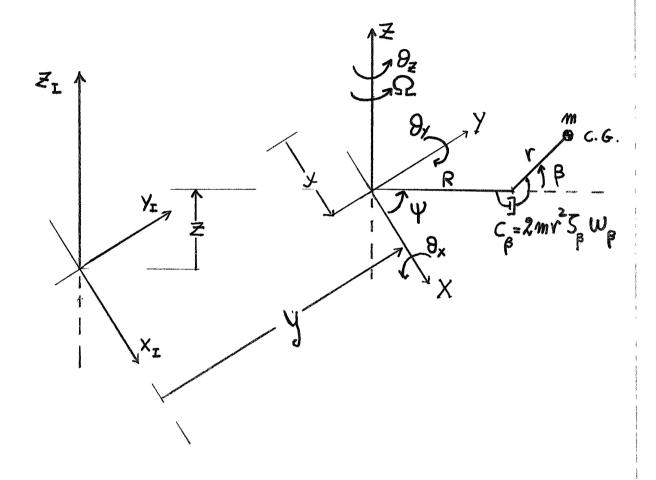


FIGURE D. 2-1: VERTICAL BIFILAR MATH MODEL

$$n = \sqrt{\frac{R+r}{r}}$$
 (TUNING ~ PER REV) (18)

$$\{X_{\mathcal{I}}\} = \{X\} + [\Theta_{\mathcal{I}}] \cdot [\Theta_{\mathcal{I}}] \cdot [\Theta_{\mathcal{I}}] \cdot \{R\{Y_i\} + r[B] \cdot \{Y_i\}\}$$
 (19)

WHERE:

$$\begin{bmatrix} \Theta_{\overline{z}} \end{bmatrix} = \begin{bmatrix} \cos \theta_{\overline{z}} & -\sin \theta_{\overline{z}} & 0 \\ \sin \theta_{\overline{z}} & \cos \theta_{\overline{z}} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Theta_{\overline{x}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_{\overline{x}} & -\sin \theta_{\overline{x}} \\ 0 & \sin \theta_{\overline{x}} & \cos \theta_{\overline{x}} \end{bmatrix}$$

$$\begin{bmatrix} \Theta_{\mathbf{x}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_{\mathbf{x}} & -\sin \theta_{\mathbf{x}} \\ 0 & \sin \theta_{\mathbf{x}} & \cos \theta_{\mathbf{x}} \end{bmatrix}$$

$$\left[\Theta_{y}\right] = \begin{bmatrix} \cos \theta_{y} & 0 & \sin \theta_{y} \\ 0 & 1 & 0 \\ -\sin \theta_{y} & 0 & \cos \theta_{y} \end{bmatrix} \qquad \left[\Psi\right] = \begin{bmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \Psi \end{bmatrix} = \begin{bmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} B \end{bmatrix} = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix}$$

$$\{V_i\} = \{ \begin{matrix} 0 \\ 0 \\ 1 \end{matrix} \}$$

FIGURE D.2-2: POSITION VECTOR FOR VERTICAL BIFILAR MASS

$$(m_{e}+M_{T})\ddot{x} + (2m_{e}w_{x}5_{x})\dot{x} + (m_{e}w_{x}^{2})x$$

$$+ \sum_{k=1}^{N} m_{k} \left\{ -\left[(r_{k}+R_{k}) \sin \psi_{k} \right] \ddot{\theta}_{z} - \left[2\Omega(r_{k}+R_{k}) \cos \psi_{k} \right] \dot{\theta}_{z} \right\}$$

$$+ \left[\Omega^{2}(r_{k}+R_{k}) \sin \psi_{k} \right] \theta_{z} - \Omega^{2}(r_{k}+R_{k}) \cos \psi_{k} = F_{x}$$

$$(20)$$

Y- EQUATION

$$(m_{G} + M_{T}) \dot{y} + (2m_{G} w_{y} 5_{y}) \dot{y} + (m_{G} w_{y}^{2}) \dot{y}$$

$$+ \sum_{k=1}^{N} m_{k} \left\{ \left[(r_{k} + R_{k}) \cos \psi_{k} \right] \dot{\theta}_{z} - \left[2\Omega (r_{k} + R_{k}) \sin \psi_{k} \right] \dot{\theta}_{z} \right.$$

$$- \left[\Omega^{2} (r_{k} + R_{k}) \cos \psi_{k} \right] \dot{\theta}_{z} - \Omega^{2} (r_{k} + R_{k}) \sin \psi_{k} \right\} = F_{y}$$

$$(21)$$

FIGURE D. 2-3: LINEAR EQUATIONS OF MOTION FOR VERTICAL BIFILAR

Z-EQUATION

$$(m_{e}+M_{T})\ddot{z} + (2m_{e}w_{z})\ddot{z} + (m_{e}w_{z})\ddot{z}$$

$$+\sum_{k=1}^{N}m_{k}\left\{(r_{k})\mathring{\beta}_{k} + \left[(r_{k}+R_{k})\sin\psi_{k}\right]\mathring{\partial}_{x} + \left[(r_{k}+R_{k})\cos\psi_{k}\right]\mathring{\partial}_{y}$$

$$+\left[2\Omega(r_{k}+R_{k})\cos\psi_{k}\right]\mathring{\partial}_{x} + \left[2\Omega(r_{k}+R_{k})\sin\psi_{k}\right]\mathring{\partial}_{y}$$

$$-\left[\Omega^{2}(r_{k}+R_{k})\sin\psi_{k}\right]\partial_{x} + \left[\Omega^{2}(r_{k}+R_{k})\cos\psi_{k}\right]\partial_{y}\right\} = F_{z}$$

$$(22)$$

FIGURE D, 2-3: LINEAR EQUATIONS OF MOTION FOR VERTICAL BIFILAR (CONTINUED)

$$\left\{m_{G} + \left[\sum_{k=1}^{N} m_{k} (r_{k} + R_{k})^{2} \sin^{2} \psi_{k}\right]\right\} \hat{\theta}_{X}$$

$$+\left\{2m_{\varepsilon}\omega_{\theta_{X}}\delta_{\theta_{X}}+\left[\sum_{k=1}^{N}2m_{k}\Omega(r_{k}+R_{k})\cos\psi_{k}\sin\psi_{k}\right]\right\}\delta_{X}$$

$$+ \sum_{k=1}^{N} M_{k} \left\{ \left[r_{k} (r_{k} + R_{k}) \sin \psi_{k} \right] \beta_{k}^{s} + \left[(r_{k} + R_{k}) \sin \psi_{k} \right]^{s} Z \right\}$$

+[2\Pi(\text{r}_k+\text{R}_k)\sim^2\pi_k]\delta_y +[\text{r}_k\Pi(\text{r}_k+\text{R}_k)\sim\pi_k]\beta_k
+[\Pi^2(\text{r}_k+\text{R}_k)\sim\pi_k\cos\pi_k]\delta_y\] =
$$M_X$$
 (23)

FIGURE D. 2-3: LINEAR EQUATIONS OF MOTION FOR VERTICAL BIFILAR (CONTINUED)

$$\left\{ m_{G} + \left[\sum_{k=1}^{N} m_{K} (r_{k} + R_{k})^{2} \cos^{2} \psi_{k} \right] \right\} \stackrel{\circ}{\theta}_{y} + \left(m_{G} \omega_{\theta y}^{2} \right) \theta_{y}$$

$$+\left\{2m_{\varepsilon}W_{\partial\gamma}S_{\partial\gamma}-2\Omega\left[\sum_{k=1}^{N}m_{k}(r_{k}+R_{k})^{2}S_{i}m_{k}(cosy_{k})\right\}\delta_{\gamma}\right\}$$

+
$$\sum_{k=1}^{N} m_{k} \left\{ -\left[r_{k} (r_{k} + R_{k}) \cos \psi_{k} \right] \beta_{k} - \left[(r_{k} + R_{k}) \cos \psi_{k} \right] \mathcal{Z} \right\}$$

$$-\left[2\Omega\left(r_{k}+R_{k}\right)^{2}\cos^{2}\psi_{k}\right]\theta_{x}+\left[r_{k}\Omega^{2}\left(r_{k}+R_{k}\right)\cos\psi_{k}\right]\beta_{k}=M_{y}$$
(24)

$$\left[M_G + \sum_{k=1}^{N} M_K (r_k + R_k)^2 \right] \hat{\theta}_Z$$

$$+ [2m_{G}\omega_{\partial_{Z}}S_{OZ}]^{\circ}\partial_{Z} + (m_{G}\omega_{OZ}^{2})\partial_{Z}$$

$$+\sum_{k=1}^{N} m_{k} \left\{ -\left[\left(r_{k} + R_{k} \right) sim \psi_{k} \right] \ddot{X} + \left[\left(r_{k} + R_{k} \right) cos \psi_{k} \right] \ddot{Y} \right\}$$

$$-\left[2\Omega\left(r_{k}+R_{k}\right)\cos\psi_{k}\right]\dot{x}-\left[2\Omega\left(r_{k}+R_{k}\right)\sin\psi_{k}\right]\dot{y}=M_{Z}$$
(25)

$$(m_k r_k) \ddot{z} + [m_k r_k (r_k + R_k) \sin \psi_k] \ddot{\theta}_x + (m_k r_k^2) \ddot{\beta}$$

$$-\left[m_{k}r_{k}\left(r_{k}+R_{k}\right)\cos\psi_{k}\right]\vartheta_{y}+\left[2m_{k}r_{k}^{2}\zeta_{p_{k}}w_{p_{k}}\right]\beta_{k}$$

+
$$\left[2m_{k}r_{k}\Omega\left(r_{k}+R_{k}\right)\cos\psi_{k}\right]\hat{\theta}_{x}$$

$$+\left[2m_{k}r_{k}\Omega\left(r_{k}+R_{k}\right)siny_{k}\right]\vartheta_{y}+\left[m_{k}r_{k}\Omega^{2}\left(r_{k}+R_{k}\right)\right]\beta_{k}=0$$
(26)

$$\beta = \frac{1}{N}\beta_0 + \frac{2}{N}\beta_S SIM\psi + \frac{2}{N}\beta_C COS\psi \qquad (27)$$

$$(m_G + M_T)\ddot{X} + (2m_G \omega_X S_X)\dot{X} + (m_G \omega_X^2)\dot{X} = F_X \quad (28)$$

Y- EQUATION

$$(m_{G} + M_{\tau})\ddot{y} + (2m_{G}\omega_{Y}S_{Y})\dot{y} + (m_{G}\omega_{Y}^{2})y = Fy \qquad (29)$$

Z- EQUATION

$$(m_G + M_T)\ddot{Z} + (2m_G w_z S_z)\dot{Z} + (m_G w_z^2)Z + mr\beta_o = F_Z$$
 (30)

FIGURE D.2-4: VERTICAL BIFILAR EQUATIONS IN FIXED SYSTEM COORDINATES

$$[m_{G} + \frac{1}{2}M_{T}(r+R)^{2}]\ddot{\theta}_{x} + (2m_{G}\omega_{\theta x}S_{\theta x})\dot{\theta}_{x} + (m_{G}\omega_{\theta x}^{2})\theta_{x}$$

$$+[m(r+R)r]\ddot{\beta}_{s} - [2mr\Omega(r+R)]\dot{\beta}_{c} + [M_{T}\Omega(r+R)^{2}]\dot{\theta}_{y} = M_{x}$$
(31)

By - EQUATION

$$\left[m_{G} + \frac{1}{2}M_{T}(r+R)^{2}\right] \ddot{\partial}_{y} + \left(2m_{G}\omega_{\theta\gamma}\mathcal{T}_{\theta\gamma}\right) \dot{\partial}_{y} + \left(m_{G}\omega_{\theta\gamma}^{2}\right) \partial_{y}
+ \left[-mr(r+R)\right] \ddot{\beta}_{c} - \left[2mr\Omega(r+R)\right] \dot{\beta}_{s} - \left[M_{T}\Omega(r+R)^{2}\right] \dot{\partial}_{x} = M_{y}$$
(32)

$$\left[m_{G} + M_{T}(r+R)^{2}\right] \ddot{\partial}_{z} + \left(2m_{G}\omega_{\theta z} S_{\theta z}\right) \dot{\partial}_{z} + \left(m_{G}\omega_{\theta z}^{2}\right) \partial_{z} = M_{z}$$
(33)

FIGURE D.2-4: VERTICAL BIFILAR EQUATIONS IN FIXED SYSTEM COORDINATES (CONTINUED)

$$(M_{\tau}r)\ddot{z} + (mr^{2})\ddot{\beta}_{o} + (2mr^{2}5_{\beta}\omega_{\beta})\dot{\beta}_{o} + [mr\Omega^{2}(r+R)]\beta_{o} = 0$$
(34)

Bs - EQUATION

$$\left[\frac{M_{\tau}}{2}r(r+R)\right]\ddot{\theta}_{x} + \left(mr^{2}\right)\ddot{\beta}_{s} + \left(2mr^{2}S_{\mu}\omega_{\mu}\right)\dot{\beta}_{s}$$

$$-\left(2mr^{2}\Omega\right)\dot{\beta}_{c} + \left[M_{\tau}r\Omega(r+R)\right]\dot{\theta}_{y} + \left(mrR\Omega^{2}\right)\beta_{s}$$

$$-\left(2mr^{2}S_{\mu}\omega_{\mu}\Omega\right)\beta_{c} = 0$$
(35)

BC - EQUATION

$$-\left[\frac{M_{T}}{2}r(r+R)\right]\ddot{\theta}_{y} + (mr^{2})\ddot{\beta}_{c} + (2mr^{2}S_{\rho}w_{\rho})\dot{\beta}_{c} + (2mr^{2}\Omega)\dot{\beta}_{s}$$

$$+\left[M_{T}r\Omega(r+R)\right]\dot{\theta}_{x} + (mrR\Omega^{2})\beta_{c} + (2mr^{2}S_{\rho}w_{\rho}\Omega)\beta_{s} = 0 \quad (36)$$

FIGURE D.2-4: VERTICAL BIFILAR EQUATIONS IN FIXED SYSTEM COORDINATES (CONCLUDED)

D.3 Rotor Equations With Hover Aerodynamics

The rotor equations of motion have been derived with five hub degrees of freedom (X, Y, Z, θ_X , θ_Y), as well as with four coupled flap-lag flexible blade bending, two torsional, a rigid flapping and a rigid lead-lag degrees of freedom. Definition of the coordinate system is shown in Figure D.3-1. A detailed derivation of the rotor equations of motion are presented in Reference 1. For completeness sake, these equations are included herewith.

The equations of motion are shown on pp 305 to 331. The airframe generalized coordinates have been utilized for the hub flexibilities. The first equation is for the fixed system, and the other four are rotor equations, i.e. bending, torsion, rigid flapping and rigid lead-lag equations (37)-(41) respectively. These equations consist of the acceleration, velocity and displacement coefficients which account for the left-hand-side of the Lagrange's equations of motion. The right-hand-side of the Lagrange's equations, the generalized forces, are shown by equations (42)-(46). In every equation, all generalized coordinates and physical properties associated with the rotor system have a subscript n, the blade number. The definition of all parameters used in all rotor equations are described in the list of symbols immediately following the equations (pp 332 to 338).

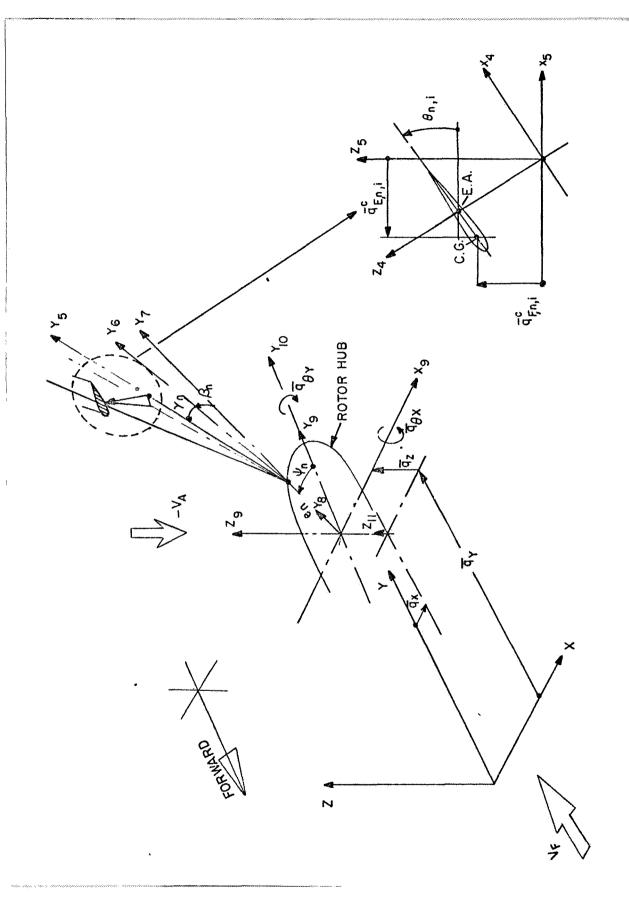


Figure 0.3-1: Aeroelastic Rotor Stability Analysis Coordinate System

Airframe Mode Equations

$$\begin{cases} \sum_{n=1}^{NA} \left[\delta^{R-e} \operatorname{mdr} \{ \phi_{\mathbf{X},i} (\phi_{\mathbf{X},i} + \phi_{\theta\mathbf{Y},i} [b_2 + r \theta_o]) + \phi_{\mathbf{Y},j} (\phi_{\mathbf{Y},i} - \phi_{\theta\mathbf{X},i} [b_2 + r \theta_o]) \right. \\ + \phi_{\mathbf{Z},j} (\phi_{\mathbf{Z},i} + \phi_{\theta\mathbf{X},i} [(a_2 - r \gamma_o) \sin \psi + (e + r + a_2 \gamma_o - b_2 \beta_o) \cos \psi] \\ + \phi_{\theta\mathbf{Y},i} [(e + r + a_2 \gamma_o - b_2 \beta_o) \sin \psi - (a_2 - r \gamma_o) \cos \psi]) + \phi_{\theta\mathbf{Y},j} ((b_2 + r \theta_o) \phi_{\mathbf{X},i} + \phi_{\mathbf{Z},i} [(e + r + a_2 \gamma_o - b_2 \beta_o) \sin \psi - (a_2 - r \gamma_o) \cos \psi]) + \phi_{\theta\mathbf{X},j} (-(b_2 + r \theta_o) \phi_{\mathbf{X},i} + \phi_{\mathbf{Z},i} [(e + r + a_2 \gamma_o - b_2 \beta_o) \cos \psi + (a_2 - r \gamma_o) \sin \psi]) \\ + \phi_{\theta\mathbf{Y},j} (\phi_{\theta\mathbf{Y},i} [(-a_2 (a_2 \gamma_o - b_2 \beta_o) - (r + e) (a_2 - r \gamma_o)) \sin 2\psi + ((r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \sin^2 \psi + a_2 (a_2 - 2r \gamma_o) \cos^2 \psi + b_2 (b_2 + 2r \beta_o)] \\ + \phi_{\theta\mathbf{X},i} [b_2 (-a_2 (a_2 - 2r \gamma_o) + (r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \sin 2\psi + (-(r + e)(a_2 - r \gamma_o) - a_2 (a_2 \gamma_o - b_2 \beta_o)) \cos 2\psi]) + \phi_{\theta\mathbf{X},j} (\phi_{\theta\mathbf{Y},i} [b_2 (-a_2 (a_2 - 2r \gamma_o) + (r + e)^2 + 2(r + e) (a_2 - r \gamma_o)) + (r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \cos 2\psi + (r + e) (a_2 - r \gamma_o) + (r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \cos 2\psi + \phi_{\mathbf{X},j} (\phi_{\theta\mathbf{Y},j} [b_2 (-a_2 (a_2 - 2r \gamma_o) + (r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \cos 2\psi + (r + e) (a_2 - r \gamma_o)) \sin 2\psi + ((r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \cos^2 \psi + a_2 (a_2 - 2r \gamma_o) \sin^2 \psi + (r + e)^2 + 2(r + e) (a_2 \gamma_o - b_2 \beta_o)) \cos^2 \psi + a_2 (a_2 - 2r \gamma_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o)) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o - b_2 \phi_o) \sin^2 \psi + \phi_{\mathbf{X},j} (cos^2 \phi_o - b_2 \phi_o$$

```
+ \phi_{\theta X,i} (-q'_{E0} \cos \theta_0 + q'_{F0} \sin \theta_0) \sin 2\psi) + \phi_{\theta Y,j} (\phi_{\theta Y,i} (\cos^2 \psi - \gamma_0 \sin 2\psi))
          + \phi_{\theta X,i} (- \gamma_0 \cos 2\psi - \frac{1}{2} \sin 2\psi)) + \phi_{\theta X,j} (\phi_{\theta Y,i} (- \gamma_0 \cos 2\psi - \frac{1}{2} \sin 2\psi)
         + \phi_{\theta X,i}(\sin^2 \psi + \gamma_0 \sin^2 \psi)) + I_Z dr \{ \phi_{\theta Y,j} q^*_{FO}(\phi_{\theta Y,i} \sin^2 \theta \sin^2 \psi) \}
         + \phi_{\theta X, i} \sin^{\theta} \cos^{2} \psi) + \phi_{\theta X, j} q^{\dagger}_{FO} (\phi_{\theta Y, i} \sin^{\theta} \cos^{2} \psi - \phi_{\theta X, i} \sin^{\theta} \cos^{1} 2\psi)
         + \phi_{\theta Y,j}(\phi_{\theta Y,i}(\sin^2\theta_0\sin^2\psi + (\gamma_0\sin^2\theta_0 + \frac{1}{2}\beta_0\sin^2\theta_0)\sin^2\psi)
         + \phi_{\theta X,i}(\frac{1}{2}\sin^2\theta_0\sin^2\psi + (\gamma_0\sin^2\theta_0 + \frac{1}{2}\beta_0\sin^2\theta_0)\cos^2\psi))
         + \phi_{\theta X,j}(\phi_{\theta Y,i}(\frac{1}{2}\sin^2\theta_0\sin^2\psi + (\gamma_0\sin^2\theta_0 + \frac{1}{2}\beta_0\sin^2\theta_0)\cos^2\psi)
        + \phi_{\theta X,i} (\sin^2 \theta_0 \cos^2 \psi - (\gamma_0 \sin^2 \theta_0 + \frac{1}{2} \beta_0 \sin^2 \theta_0) \sin^2 \psi)) \} \right] \ddot{q}_i \Big\}
     + \left\{\sum_{i=1}^{\mathbf{MA}} \left[\phi_{\theta X,i}\phi_{\theta X,j}\right]_{FA} + \phi_{\theta Y,i}\phi_{\theta Y,j}\right]_{L} + \phi_{Z,i}\phi_{Z,j}M_{S} = \frac{1}{q_{i}} + \left\{M_{A,j}\right]_{q_{j}}^{\mathbf{T}}
       + a_2 \beta_0 \cos \psi - b_2 \sin \psi + \phi_{Z,j} a_2 + \phi_{\theta Y,j} [((a_2^2 + b_2^2) \gamma_0 + a_2(r + e)) \sin \psi]
        - (a_2(a_2 - r\gamma_0) + b_2(b_2 + r\beta_0))\cos\psi] + \phi_{\theta X,j}[(a_2(a_2 - r\gamma_0))
         +b_2(b_2+r\beta_0))\sin\psi+((a_2^2+b_2^2)\gamma_0+a_2(r+e))\cos\psi]
         + I_{X} dr \{ \phi_{\theta Y,j} q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\theta_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\phi_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\theta_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\phi_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\phi_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\phi_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\phi_{o} sin\psi + \phi_{\theta X,j} q'_{EO} cos\phi_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} cos\phi_{o} sin\psi + \phi_{\phi X,j} q'_{EO} cos\phi_{o} cos\psi \} + I_{Y} dr \{ \phi_{\theta Y,j} (-q'_{EO} co
         + q'_{FO} \sin\theta_{o}) \sin\psi + \phi_{\theta X,j} (-q'_{EO} \cos\theta_{o} + q'_{FO} \sin\theta_{o}) \cos\psi + \phi_{\theta Y,j} (\gamma_{o} \sin\psi) + q'_{EO} \cos\theta_{o} + q'_{EO} \sin\theta_{o}) \cos\psi + \phi_{\theta Y,j} (\gamma_{o} \sin\psi) + q'_{EO} \cos\theta_{o} + q'_{EO} \sin\theta_{o}) \cos\psi + \phi_{\theta Y,j} (\gamma_{o} \sin\psi) + q'_{EO} \cos\theta_{o} + q'_{EO} \sin\theta_{o}) \cos\psi + \phi_{\theta Y,j} (\gamma_{o} \sin\psi) + q'_{EO} \cos\theta_{o} + q'_{EO} \sin\theta_{o}) \cos\psi + \phi_{\theta Y,j} (\gamma_{o} \sin\psi) + q'_{EO} \cos\theta_{o} + q'_{EO} \sin\theta_{o}) \cos\psi + \phi_{\theta Y,j} (\gamma_{o} \sin\psi) + q'_{EO} \sin\theta_{o}) \cos\psi + q'_{EO} \sin\theta_{o}) \cos\psi + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\theta_{o}) \cos\psi + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o})  q'_{EO} \sin\phi_{o}) \cos\psi + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o}) \cos\psi + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q'_{EO} \sin\phi_{o} + q
         -\cos\psi) + \phi_{\theta X,j}(\gamma_0 \cos\psi + \sin\psi) + I_Z dr \{-\phi_{\theta Y,j} q_{FO}^* \sin\theta_0 \sin\psi\}
          -\phi_{\theta X,j}q_{FO}^{\dagger}\sin\theta_{o}\cos\psi\}\Big]\phi_{\theta}\ddot{\theta}_{T}\Big\}+\Big\{\sum_{n=1}^{N}\Big[\int_{0}^{R-e}m\mathrm{d}r\{\phi_{X,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}+r\beta_{o}+r\beta_{o})\sin\psi-\phi_{Y,j}(b_{2}
         + r\beta_0)\cos \psi + \phi_{Z,j}(r + a_2\gamma_0 - b_2\beta_0) + \phi_{\theta Y,j}[(e(a_2\gamma_0 - b_2\beta_0) + r(r-+ e + 2a_2\gamma_0)
           + b_2^2 | sin \psi - (a_2^2(a_2\gamma_0 - b_2\beta_0) + r(a_2 - r\gamma_0))\cos\psi + \phi_{0X,j}[(a_2(a_2\gamma_0 - b_2\beta_0))
          + r(a_2 - r\gamma_0))sin\psi + (e(a_2\gamma_0 - b_2\beta_0) + r(r + e + 2a_2\gamma_0) + b_2^2)cos\psi]
+ I_X dr\{-\phi_{\theta Y,j} q_{EO}^{\dagger} cos\theta_{0} cos\psi + \phi_{\theta X,j} q_{EO}^{\dagger} cos\theta_{0} sin\psi + \phi_{\theta Y,j} (cos^2\theta_{0} sin\psi)
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+ (\gamma_0 \cos^2 \theta_0 - \frac{1}{28} \sin^2 \theta_0) \cos \psi) + \phi_{0X,j} (\cos^2 \theta_0 \cos \psi - (\gamma_0 \cos^2 \theta_0))
-\frac{1}{2}\beta_{0}\sin 2\theta_{0})\sin \psi)\} + I_{\Upsilon}dr\{\phi_{\theta\Upsilon}, j(q'_{EO}\cos\theta_{0} - q'_{FO}\sin\theta_{0})\cos\psi\}
+ \phi_{\theta X,j} (-q'_{EO}^{\cos\theta} + q'_{FO}^{\sin\theta})^{\sin\psi} + \phi_{\theta X,j}^{\gamma} (-q'_{\theta Y,j}^{\cos\psi})^{\gamma}
+ \mathrm{I}_{\mathrm{Z}}^{\mathrm{dr}\{\phi_{\Theta Y,j}q^{*}_{FO}\sin\theta_{O}\cos\psi - \phi_{\Theta X,j}q^{*}_{FO}\sin\theta_{O}\sin\psi + \phi_{\Theta Y,j}(\sin^{2}\theta_{O}\sin\psi + \phi_{O})\}
+ \left( \gamma_o \sin^2 \theta_o + \frac{1}{2} \beta_o \sin 2\theta_o \right) \cos \psi \right) + \phi_{\theta X,j} (\sin^2 \theta_o \cos \psi - (\gamma_o \sin^2 \theta_o \cos \psi) + \phi_{\theta X,j} (\sin^2 \theta_o \cos \psi) +
+ \frac{1}{2} \beta_{0} \sin 2\theta_{0} \sin \psi) \} \right] \stackrel{..}{\beta} + \left\{ \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \{ \phi_{X,j} (-(a_{2} - r\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi \right] \right\} \right\} + \left\{ \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \{ \phi_{X,j} (-(a_{2} - r\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi \right] \right\} \right\} + \left\{ \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \{ \phi_{X,j} (-(a_{2} - r\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi \right] \right\} \right\} + \left\{ \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \{ \phi_{X,j} (-(a_{2} - r\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi \right] \right\} + \left\{ \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \{ \phi_{X,j} (-(a_{2} - r\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi - (a_{2}\gamma_{0}) \sin \psi \right] \right\} \right\}
+ r) \cos \psi) + \phi_{Y,j} (-(a_2 \gamma_0 + r) \sin \psi + (a_2 - r \gamma_0) \cos \psi) + \phi_{Z,j} a_2 \beta_0
+ \phi_{\theta Y,j} [(-b_2(a_2 - r\gamma_0) + a_2e\beta_0)\sin\psi + (-(a_2^2 + r^2)\beta_0 - b_2(a_2\gamma_0 + r))\cos\psi]
 + \phi_{0X,j} [((a_2^2 + r^2)\beta_0 + b_2(a_2\gamma_0 + r))\sin\psi + (-b_2(a_2 - r\gamma_0) + a_2e\beta_0)\cos\psi] \}
  + \text{I}_{\chi}^{\text{dr}\{-\phi_{\theta Y},j^{q'}=0} \sin\theta_{0} \cos\psi + \phi_{\theta X,j^{q'}=0} \sin\theta_{0} \sin\psi + \phi_{\theta Y,j^{q'}=0} \sin\theta_{0} \sin\psi
  + \left( \frac{1}{2} \gamma_0 \sin 2\theta_0 - \beta_0 \sin^2\theta_0 \right) \cos \psi \right] + \phi_{\theta X,j} \left[ \frac{1}{2} \sin 2\theta_0 \cos \psi - \left( \frac{1}{2} \gamma_0 \sin 2\theta_0 - \beta_0 \sin^2\theta_0 \right) \sin \psi \right] \right\}
    + I_{Y}dr\{\phi_{\theta Y,j}(q'_{EO}sin\theta_{o} + q'_{FO}cos\theta_{o})cos\psi + \phi_{\theta X,j}(-q'_{EO}sin\theta_{o})
      - q'_{FO}^{\cos\theta}_{o}^{\sin\psi} + I_{Z}^{dr} \{- \phi_{\theta Y,j}^{} q'_{FO}^{\cos\theta}_{o}^{\cos\psi} + \phi_{\theta X,j}^{} q'_{FO}^{}^{\cos\theta}_{o}^{\sin\psi}
      + \phi_{\theta Y,j}[-\frac{1}{2}\sin 2\theta_0\sin \psi - (\frac{1}{2}\gamma_0\sin 2\theta_0 + \beta_0\cos^2\theta_0)\cos \psi] + \phi_{\theta X,j}[-\frac{1}{2}\sin 2\theta_0\cos \psi]
     + v_{1,i} \sin \psi + \phi_{F,i} \beta_0 \sin \psi) + \phi_{Y,j} (\phi_{E,i} (-\sin \psi - \gamma_0 \cos \psi) - v_{1,i} \cos \psi)
      -\phi_{F,i}\beta_{o}\cos\psi) + \phi_{Z,j}\phi_{F,i} + \phi_{\theta Y,j}[(\phi_{F,i}(a_{2}\gamma_{o} + r + e) + \phi_{E,i}b_{2}\gamma_{o})\sin\psi]
      +(-\phi_{F,i}(a_2-r\gamma_0)-\phi_{E,i}(b_2+r\beta_0))\cos\psi]+\phi_{\theta X,j}[(\phi_{F,i}(a_2-r\gamma_0)+\phi_{E,i}(b_2))]
      + r\beta_{0}) \sin \psi + (\phi_{E,i}b_{2}\gamma_{0} + \phi_{F,i}(a_{2}\gamma_{0} + r + e))\cos \psi] + \phi_{\partial Y,j}v_{1,i}b_{2}\sin \psi
        ^{+} \phi_{\theta X,j} v_{1,i} b_{2} cos \psi \} + I_{X} dr \{ \phi_{\theta Y,j} [cos\theta_{o} sin\psi + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} + (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o} - (\gamma_{o} cos\theta_{o
       -q'_{EO})\cos\psi \phi'_{F,i} + \phi_{\theta X,j}[\cos\theta_{o}\cos\psi - (\gamma_{o}\cos\theta_{o} - \beta_{o}\sin\theta_{o} - q'_{EO})\sin\psi]\phi'_{F,i}\}
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+ I_{Y}dr\{\{\phi_{\theta Y,j}q'_{FO}\cos\psi - \phi_{\theta X,j}q'_{FO}\sin\psi\}\phi'_{E,i}\}
          + I_Z^{dr\{\phi_{\theta Y,j}[-\sin\theta_o\sin\psi_-(\gamma_o\sin\theta_o+\beta_o\cos\theta_o+q'_{FO})\cos\psi]\phi'_{E,i}}
         + \phi_{\text{OX,j}} \left[ -\sin\theta_{\text{o}}\cos\psi + (\gamma_{\text{o}}\sin\theta_{\text{o}} + \beta_{\text{o}}\cos\theta_{\text{o}} + q'_{\text{FO}})\sin\psi \right] \phi'_{\text{E,i}} \right] q_{\text{T,i}} \left\{ -\sin\theta_{\text{o}}\cos\psi + (\gamma_{\text{o}}\sin\theta_{\text{o}} + \beta_{\text{o}}\cos\theta_{\text{o}} + q'_{\text{FO}})\sin\psi \right] \phi'_{\text{E,i}} \right\} 
      +\left\{ \frac{1}{2} \left[ \frac{1}{R_{S}} \left( \phi_{\theta X,j} I_{FA} - \phi_{\theta Y,j} I_{L} \right) + \phi_{Z,j} M_{S} \right] \ddot{X}_{A} \right\} + \left\{ \frac{1}{2} \left[ \frac{1}{R_{S}} \left( - \phi_{\theta X,j} I_{FA} - \phi_{\theta Y,j} I_{L} \right) + \phi_{Z,j} M_{S} \right] \right\}
+ \phi_{Z,j}^{M} M_{S}^{J} X_{F}^{*} \left\{ + \right\} \frac{1}{R_{S}} \phi_{\theta Y,j} I_{L} X_{L}^{*} \left\{ + \right\} \sum_{n=1}^{N} \sum_{i=1}^{NA} \int_{0}^{R-e} m dr \{2\Omega \phi_{Z,j}^{i}[\phi_{\theta X,i}((a_{2} - r\gamma_{0})\cos \psi_{X,i}((a_{2} - r\gamma_{0})
            -(e + r + a_{2}\gamma_{0} - b_{2}\beta_{0})\sin\psi) + \phi_{\theta Y,i}((e + r + a_{2}\gamma_{0} - b_{2}\beta_{0})\cos\psi)
            + (a_2 - r\gamma_0)\sin\psi)] + \Omega\phi_{\theta Y,j}[\phi_{\theta Y,i}([(r + e)^2 + 2(r + e)(a_2\gamma_0 - b_2\beta_0))]
             -a_{2}(a_{2}-r\gamma_{0})]\sin 2\psi + [-(r+e)(a_{2}-r\gamma_{0})-a_{2}(a_{2}\gamma_{0}-b_{2}\beta_{0})]2\cos 2\psi)
             + \phi_{\theta X,i}([a_2(a_2\gamma_0 - b_2\beta_0) + (r + e) (a_2 - r\gamma_0)]2sin2\psi + [(r + e)^2]
             -a_{2}(a_{2}-2r\gamma_{0})+2(r+e)(a_{2}\gamma_{0}-b_{2}\beta_{0})]\cos 2\psi-a_{2}(a_{2}-2r\gamma_{0})-(r+e)^{2}
               -2(r+e)(a_{2}\gamma_{0}-b_{2}\beta_{0}))]+\Omega\phi_{\theta X,j}[\phi_{\theta Y,i}([a_{2}(a_{2}\gamma_{0}-b_{2}\beta_{0})+(r+e)(a_{2}\gamma_{0}-b_{2}\beta_{0})+(r+e)(a_{2}\gamma_{0}-b_{2}\beta_{0})]
            - r\gamma_{0})]2sin2\psi + [- a_{2}(a_{2} - 2r\gamma_{0}) + (r + e)^{2} + 2(r + e)(a_{2}\gamma_{0} - b_{2}\beta_{0})]cos2\psi
               +a_2(a_2-2r\gamma_0)+(r+e)^2+2(r+e)(a_2\gamma_0-b_2\beta_0))+\phi_{0X,i}([-(r+e)^2+2(r+e)(a_2\gamma_0-b_2\beta_0)))
            -2(r+e)(a_{2}\gamma_{0}-b_{2}\beta_{0})+a_{2}(a_{2}-r\gamma_{0})]\sin 2\psi+[(r+e)(a_{2}-r\gamma_{0})]\sin 2\psi
               + \ a_{2}(a_{2}\gamma_{o} - b_{2}\beta_{o})]2\cos 2\psi)]] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,j}[-\phi_{\theta Y,i}\cos\theta_{o}\cos 2\psi)\}] + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})\} + I_{X}dr\{2\Omega q'_{EO}(\phi_{\theta Y,i})
                + \phi_{\theta X,i}^{\cos\theta}^{\sin2\psi} + \phi_{\theta X,j}^{\cos\theta}^{\sin2\psi} + \phi_{\theta X,i}^{\cos\theta}^{\cos2\psi})
                 + \Omega(\phi_{\theta Y,j}[\phi_{\theta Y,i}(\cos^2\theta_0\sin^2\psi + (2\gamma_0\cos^2\theta_0 - \beta_0\sin^2\theta_0)\cos^2\psi)
                  + \phi_{\theta X,i} (\cos^2 \theta_0 \cos 2\psi - (2\gamma_0 \cos^2 \theta_0 - \beta_0 \sin 2\theta_0) \sin 2\psi) - \phi_{\theta X,i} \sin^2 \theta_0]
                   + \phi_{0X,j}[\phi_{0Y,i}(\cos^2\theta_0\cos2\psi - (2\gamma_0\cos^2\theta_0 - \beta_0\sin2\theta_0)\sin2\psi)]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           - 10
                 + \phi_{\theta X,i} (- \cos^2\theta_0 \sin^2\theta - (2\Upsilon_0 \cos^2\theta_0 - \beta_0 \sin^2\theta_0)\cos^2\theta) + \phi_{\theta Y,i}\sin^2\theta_0)
                   + I_{Y}dr{2\Omega(\phi_{\theta Y,j}[\phi_{\theta Y,i}(q'_{EO}^{cos\theta}_{o} - q'_{FO}^{sin\theta}_{o})cos2\psi + \phi_{\theta X,i}(- q'_{EO}^{cos\theta}_{o})
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+ q'_{FO}^{\sin\theta_0})\sin2\psi] + \phi_{\theta X,j}[\phi_{\theta Y,i}(-q'_{EO}^{\cos\theta_0})]
  + q'_{FO}sin\theta_o)sin2\psi + \phi_{\theta X,i}(- q'_{EO}cos\theta_o + q'_{FO}sin\theta_o)cos2\psi])
     + \Omega(\phi_{\theta Y,j} [\phi_{\theta Y,i} (-2\gamma_{o} \cos 2\psi - \sin 2\psi) + \phi_{\theta X,i} (-\cos 2\psi + 2\gamma_{o} \sin 2\psi)]
       + \phi_{\theta X,j} [\phi_{\theta Y,i} (-\cos 2\psi + 2\gamma_0 \sin 2\psi) + \phi_{\theta X,i} (2\gamma_0 \cos 2\psi + \sin 2\psi)]) \}
     + I_Z dr\{2\Omega q'_{FO}(\phi_{\theta Y,j}[\phi_{\theta Y,i}\sin\theta_{o}\cos2\psi - \phi_{\theta X,i}\sin\theta_{o}\cos2\psi] + \phi_{\theta X,j}[
-\phi_{\theta Y,i} \sin^{\theta} \cos^{1} 2\psi -\phi_{\theta X,i} \sin^{\theta} \cos^{2} \psi]) + \Omega(\phi_{\theta Y,j} [\phi_{\theta Y,i} (\sin^{2} \theta_{o} \sin^{2} \psi + (2\gamma_{o} \sin^{2} \theta_{o} \sin^{2} \psi) + (2\gamma_{o} \sin^{2} \theta_{o} \sin^{2} \psi)]
    +\beta_0 \sin 2\theta_0) \cos 2\psi) + \phi_{\theta X,i} (\sin^2 \theta_0 \cos 2\psi - (2\gamma_0 \sin^2 \theta_0 + \beta_0 \sin 2\theta_0) \sin 2\psi)
     -\phi_{\theta X,i} \cos^2 \theta_0 + \phi_{\theta X,j} [\phi_{\theta Y,i} (\sin^2 \theta_0 \cos 2\psi - (2\gamma_0 \sin^2 \theta_0 + \beta_0 \sin 2\theta_0) \sin 2\psi)]
     + \phi_{\theta X,i}(-\sin^2\theta_0\sin^2\theta_0 - (2\gamma_0\sin^2\theta_0 + \beta_0\sin^2\theta_0)\cos^2\theta)
     + \phi_{\theta Y, i} \cos^2 \theta_{0} ]) ] \dot{q}_{j} + \left\{ 2 \zeta_{A, j} M_{A, j} \omega_{A, j} \dot{q}_{j} \right\}
    + \left\{ \sum_{n=1}^{N} \left[ \delta^{R-e} \operatorname{mdr} \left\{ 2\Omega \left( \phi_{X,j} \left( \left( b_{2} \gamma_{o} + a_{2} \beta_{o} \right) \cos \psi + b_{2} \sin \psi \right) \right. \right] \right\} \right\} \right\}
     + \phi_{Y_3,j}((b_2\gamma_0 + a_2\beta_0)\sin\psi - b_2\cos\psi) + \phi_{\theta Y_3,j}(b_2(b_2))
      + r\beta_0) sin\psi + b_2(a_2\beta_0 + b_2\gamma_0)\cos\psi) + \phi_{\theta X,j}(-b_2(b_2\gamma_0 + a_2\beta_0)\sin\psi)
     + b_2(b_2 + r\beta_0)\cos\psi))\} + I_X dr\{\Omega(\phi_{\theta Y,j}[\cos 2\theta_0 \sin \psi + (\gamma_0 \cos 
     -\beta_0 \sin 2\theta_0) \cos \psi + \phi_{0X,j} [\cos 2\theta_0 \cos \psi - (\gamma_0 \cos 2\theta_0 - \beta_0 \sin 2\theta_0) \sin \psi]) \}
      + I_{Y}dr\{\Omega(\phi_{\theta Y,j}(\gamma_{o}\cos\psi + \sin\psi) + \phi_{\theta X,j}(\cos\psi - \gamma_{o}\sin\psi))\}
      + I_{z} dr{\Omega (\phi_{\theta Y}, J[-cos2\theta_{o} sin\psi - (\gamma_{o} cos2\theta_{o} - \beta_{o} sin2\theta_{o}) cos\psi]
      + \phi_{\theta X,j} [-\cos 2\theta_0 \cos \psi + (\gamma_0 \cos 2\theta_0 - \beta_0 \sin 2\theta_0) \sin \psi]) \} \phi_{\theta} \phi_{T} 
      +  \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega(\phi_{X,j}(b_2 + r\beta_0)\cos\psi + \phi_{Y,j}(b_2 + r\beta_0)\sin\psi \right\} \right] 
                                                                                                                                                                                                                                                                                                                                                                                                                     is it
      + \phi_{\theta Y.,j}b_2(b_2 + 2r\beta_0)\cos\psi - \phi_{\theta X,j}b_2(b_2 + 2r\beta_0)\sin\psi)
                                                                                                                                                                                                                                                                                                                                                                                                                                Å,
       + I_{X}dr\{\Omega(\phi_{\theta Y,j}\cos 2\theta_{o}\cos \psi - \phi_{\theta X,j}\cos 2\theta_{o}\sin \psi)\} + I_{Y}dr\{\Omega(\phi_{\theta Y,j}\cos \psi)\}
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-\phi_{\theta X,j} \sin \psi) + I_{Z} dr \{\Omega(-\phi_{\theta Y,j} \cos 2\theta_{0} \cos \psi + \phi_{\theta X,j} \cos 2\theta_{0} \sin \psi)\} \dot{\beta} \dot{\beta}
 +  \left\{ \sum_{n=1}^{N} \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega(\phi_{X,j} \left[ -(a_2 - r\gamma_0) \cos \psi + (a_2 \gamma_0 + r) \sin \psi \right] \right] \right\} \right\} 
       + \phi_{Y,j} [ - (a_2 \gamma_0 + r) \cos \psi - (a_2 - r \gamma_0) \sin \psi ] + \phi_{\theta Y,j} [ (r^2 \beta_0 + b_2 (a_2 \gamma_0) + c_3 (a_2 \gamma_0) + c_3 (a_3 \gamma_0) + c_3 (a_3 \gamma_0) ] + \phi_{\theta Y,j} [ (r^2 \beta_0 + c_3 \gamma_0) + c_3 (a_3 \gamma_0) + c_3 (a_3 \gamma_0) + c_3 (a_3 \gamma_0) ] + \phi_{\theta Y,j} [ (r^2 \beta_0 + c_3 \gamma_0) + c_3 (a_3 \gamma_0) + c_3 (
+ r) \sin \psi - (b_2(a_2 - r\gamma_0) + a_2r\beta_0)\cos \psi + \phi_{\theta X,j}[(r^2\beta_0 + b_2(a_2\gamma_0 + r))\cos \psi]
       + (b_2(a_2 - r\gamma_0) + a_2r\beta_0)\sin\psi]) + I_Xdr\{2\Omega q'_{EO}(\phi_{\theta Y,j}\sin\theta_0\sin\psi)\}
       + \phi_{\theta X,j} \sin \theta_{0} \cos \psi) + \Omega(\phi_{\theta Y,j} [\sin 2\theta_{0} \cos \psi - (\gamma_{0} \sin 2\theta_{0} - \beta_{0}) \sin \psi]
        + \phi_{0X,j}[-\sin^2\theta_0\sin\psi - (\gamma_0\sin^2\theta_0 - \beta_0)\cos\psi])
        + I_{Y}dr\{2\Omega(\phi_{\theta Y,j}(-q'_{EO}\sin\theta_{o}-q'_{FO}\cos\theta_{o})\sin\psi+\phi_{\theta X,j}(-q'_{EO}\sin\theta_{o})\sin\psi+\phi_{\theta X,j}(-q'_{EO}\sin\theta_{o})\sin\psi\}
        -q'_{FO}\cos\theta_{o})\cos\psi) + \Omega(-\phi_{\theta Y,j}\beta_{o}\sin\psi - \phi_{\theta X,j}\beta_{o}\cos\psi)\}
        + I_{Z}^{dr} \{2\Omega q_{FO}^{\dagger}(\phi_{\theta Y,j} \cos \theta_{o} \sin \psi + \phi_{\theta X,j} \cos \theta_{o} \cos \psi) + \Omega(\phi_{\theta Y,j}^{\dagger}(-\sin 2\theta_{o} \cos \psi))\}
        + (\gamma_0 \sin 2\theta_0 + \beta_0) \sin \psi) + \phi_{\theta X,j} (\sin 2\theta_0 \sin \psi + (\gamma_0 \sin 2\theta_0 + \beta_0) \cos \psi) \} \Big] \dot{\gamma} \Big\}
    + \left\{ \sum_{m=1}^{N} \sum_{i=1}^{NE} \int_{0}^{R-e} m dr \left\{ 2\Omega(\phi_{X,j} [\phi_{E,i} (\gamma_{o} \cos \psi + \sin \psi) + \nu_{1,i} \cos \psi \right\} \right\}
     +\phi_{F,i}\beta_{o}\cos\psi + \phi_{Y,j} - \phi_{E,i}(\cos\psi - \gamma_{o}\sin\psi) + \nu_{1,i}\sin\psi
           + \phi_{F,i} \beta_0 \sin \psi ] + \phi_{\theta Y,j} [\phi_{E,i} (b_2 + r\beta_0) \sin \psi + b_2 (\phi_{F,i} \beta_0) + b_3 (\phi_{F,i} \beta_0) ]
           + \phi_{E,i} \gamma_{o}) \cos \psi ] + \phi_{\theta X,j} [ - b_{2} (\phi_{F,i} \beta_{o} + \phi_{E,i} \gamma_{o}) \sin \psi + \phi_{E,i} (b_{2} + r \beta_{o}) \cos \psi ]
             + \phi_{\theta Y,j} v_{1,i} b_{2} \cos \psi - \phi_{\theta X,j} v_{1,i} b_{2} \sin \psi) \} + I_{X} dr \{\Omega(\phi_{\theta Y,j} [(\sin \theta_{0} \cos \psi + \phi_{0})] + (\sin \theta_{0} \cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} dr \{\Omega(\phi_{0}) + (\cos \psi + \phi_{0})\} + I_{X} 
            + (q'_{E0}\sin 2\theta_{o} - \gamma_{o}\sin \theta_{o} + \beta_{o}\cos \theta_{o})\sin \psi)\phi'_{E,i}
              + (\cos\theta_{o}\cos\phi + (q'_{EO} - \gamma_{o}\cos\theta_{o} + \beta_{o}\sin\theta_{o})\sin\psi)\phi'_{F,i}]
             + \phi_{\theta X,j}[(-\sin\theta_0\sin\psi + (q^*_{B0}\sin2\theta_0 - \gamma_0\sin\theta_0 + \beta_0\cos\theta_0)\cos\psi)\phi_{E,i}^*]
             + (-\cos\theta_0\sin\psi + (q_{EO}^* - \gamma_0\cos\theta_0 + \beta_0\sin\theta_0)\cos\psi)\phi_{F,i}^*]) 6
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+ I_{Y}dr\{\Omega(\phi_{\theta Y,j} [\phi_{E,i}' (-\sin\theta_{0}\cos\psi + (-2q'_{FO}\cos^{2}\theta_{0} - q'_{EO}\sin^{2}\theta_{0})\})\}
  -\beta_{0}\cos\theta_{0} + \gamma_{0}\sin\theta_{0})\sin\psi) + \phi'_{F,1}(\cos\theta_{0}\cos\psi + (-q'_{F0}\sin2\theta_{0} + q'_{E0}\cos2\theta_{0}))\sin\psi
   -\beta_0 \sin\theta_0 - \gamma_0 \cos\theta_0 \sin\psi) \Big] + \phi_{\theta X,j} \Big[ \phi'_{E,i} (\sin\theta_0 \sin\psi + (-2q'_{FO} \cos^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \cos^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin\psi + (-2q'_{FO} \sin^2\theta_0 \sin
   - q'_{E0} \sin 2\theta_0 - \beta_0 \cos \theta_0 + \gamma_0 \sin \theta_0) \cos \psi) + \phi'_{F,i} (-\cos \theta_0 \sin \psi + (q'_{E0} \cos 2\theta_0)) + \phi'_{F,i} (-\cos \theta_0 \sin \psi + (q'_{E0} \cos 2\theta_0)) + \phi'_{E0} \sin \theta_0) + \phi'_{E0} \cos \theta_0
   -q'_{FO}\sin 2\theta_{o} - \beta_{o}\sin \theta_{o} - \gamma_{o}\cos \theta_{o})\cos \psi)])\} + I_{Z}dr\{\Omega(\phi_{\theta Y,j}[(-\sin \theta_{o}\cos \psi))])\}
  + (2q'_{FO}^{\cos 2\theta} + \gamma_0^{\sin \theta} + \beta_0^{\cos \theta})^{\sin \psi} + (-\cos \theta_0^{\cos \psi})^{\cos \psi}
+ (q'_{FO} sin2\theta_o + \gamma_o cos\theta_o + \beta_o sin\theta_o) sin\psi) \phi'_{F,i}] + \phi_{\theta X,j} [(sin\theta_o sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) + (q'_{FO} sin\psi) 
  + (2q_{FO}^{\circ}\cos^2\theta_0 + \gamma_0\sin\theta_0 + \beta_0\cos\theta_0)\cos\psi)\phi'_{E,i} + (\cos\theta_0\sin\psi + (q_{FO}^{\circ}\sin2\theta_0)\cos\psi)\phi'_{E,i}
   -q'_{EO}\cos 2\theta_0 + \gamma_0 \cos \theta_0 + \beta_0 \sin \theta_0) \cos \psi + \phi_{F,i}) \} q_{T,i}
+ \left\{ \sum_{n=1}^{N} \sum_{i=1}^{NA} \left[ \delta^{R-e} \operatorname{mdr} \left\{ \Omega^{2} \phi_{Z,j} \right] \right] \left( - \left( a_{2} - r \gamma_{0} \right) \sin \psi - \left( e + r + a_{2} \gamma_{0} \right) \right] \right\} \right\}
  -b_2^{\beta_0}\cos\psi + \phi_{\theta Y,i} ( - (e + r + a_2^{\gamma_0} - b_2^{\beta_0}) \sin\psi
 + (a_2 - r\gamma_0)\cos\psi]} \overline{q}_i + M_{A,j}\omega^2_{A,j}\overline{q}_j
 + \phi_{Y,j} [(b_2 \gamma_0 + a_2 \beta_0) \cos \psi + b_2 \sin \psi] + \phi_{\theta Y,j} [(a_2 (a_2 \gamma_0 + r + e - 2b_2 \beta_0))]
  -b_{2}^{2}\gamma_{0})sin\psi + (-a_{2}(a_{2}-r\gamma_{0})+b_{2}(b_{2}+r\beta_{0}))\cos\psi]
  +\phi_{0X,j}[(a_2(a_2-r\gamma_0)-b_2(b_2+r\beta_0))sin\psi+(a_2(a_2\gamma_0+r+e-2b_2\beta_0))]
   -b_2^2\gamma_o)\cos\psi])\}+I_{\chi}dr\{\Omega^2q'_{EO}(\phi_{\theta Y,j}\cos\theta_o\sin\psi+\phi_{\theta X,j}\cos\theta_o\cos\psi)
   + \Omega^{2}[\phi_{\theta Y,j}(\cos 2\theta_{0}\cos \psi - (\gamma_{0}\cos 2\theta_{0} - \beta_{0}\sin 2\theta_{0})\sin \psi) + \phi_{\theta X,j}(-\cos 2\theta_{0}\sin \psi)
    - (^{\gamma}_{o}\cos 2\theta_{o} - \beta_{o}\sin 2\theta_{o})\cos \psi)]\} + I_{\gamma}dr\{\Omega^{2}[\phi_{\theta Y,j}(-q_{EO}\cos \theta_{o} + q_{FO}\sin \theta_{o})\sin \psi]\}
    + \phi_{0X,j}(-q'_{EO}\cos\theta_0 + q'_{FO}\sin\theta_0)\cos\psi] + I_Z dr\{\Omega^2 q'_{FO}(-\phi_{0Y,j}\sin\theta_0\sin\psi)\}
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$$\begin{split} &- \phi_{\theta X,j} \sin \theta_0 \cos \psi) + \Omega^2 [\phi_{\theta Y,j} (-\cos 2\theta_0 \cos \psi + (\gamma_0 \cos 2\theta_0 - \theta_0 \sin 2\theta_0) \sin \psi) \\ &+ \phi_{\theta X,j} (\cos 2\theta_0 \sin \psi + (\gamma_0 \cos 2\theta_0 - \theta_0 \sin 2\theta_0) \cos \psi)])] \phi_0 \theta_T \Big\} \\ &+ \left\{ \sum_{n=1}^N \left[\delta^{R-e} \operatorname{mdr} \{\Omega^2 [-\phi_{X,j} (b_2 + r\beta_0) \sin \psi + \phi_{Y,j} (b_2 + r\beta_0) \cos \psi \right. \right. \\ &+ \phi_{\theta Y,j} ([(r+e) (\alpha_2 \gamma_0 + r - b_2 \beta_0) + r(a_2 \gamma_0 - b_2 \beta_0) - b_2 (2r\beta_0 + b_2)] \sin \psi \right. \\ &+ \left[(r+e) (\alpha_2 \gamma_0 + r - b_2 \beta_0) + b_2 (2r\beta_0 + b_2) - r^2 \gamma_0] \cos \psi) \\ &+ \phi_{\theta X,j} ([a_2 (a_2 \gamma_0 + r - b_2 \beta_0) + b_2 (2r\beta_0 + b_2) - r^2 \gamma_0] \sin \psi \right. \\ &+ \left[(r+e) (a_2 \gamma_0 + r - b_2 \beta_0) + r(a_2 \gamma_0 - b_2 \beta_0) - b_2 (b_2 + 2r\beta_0)] \cos \psi)] \Big\} \\ &+ I_X dr \{\Omega^2 Q^*_{10} (-\phi_{\theta Y,j} \cos \theta_0 \cos \psi + \phi_{\theta X,j} \cos \theta_0 \sin \psi) + \Omega^2 [\phi_{\theta Y,j} (\sin^2 \theta_0 \sin \psi) + \gamma_0 \cos^2 \theta_0 \cos \psi) + \phi_{\theta X,j} (\sin^2 \theta_0 \cos \psi + \gamma_0 \cos^2 \theta_0 \sin \psi)] \Big\} \\ &+ I_Y dr \{\Omega^2 [\phi_{\theta Y,j} (q^*_{10} \cos \theta_0 - q^*_{10} \sin \theta_0) \cos \psi + \phi_{\theta X,j} (\gamma_0 \sin \psi - \cos \psi)] \Big\} \\ &+ I_Z dr \{\Omega^2 Q^*_{10} (\phi_{\theta Y,j} \sin \theta_0 \cos \psi - \phi_{\theta X,j} \sin \theta_0 \sin \psi) + \Omega^2 [\phi_{\theta Y,j} (\cos^2 \theta_0 \sin \psi)] \Big\} \\ &+ I_Z dr \{\Omega^2 Q^*_{10} (\phi_{\theta Y,j} \sin \theta_0 \cos \psi - \phi_{\theta X,j} \sin \theta_0 \sin \psi) + \Omega^2 [\phi_{\theta Y,j} (\cos^2 \theta_0 \sin \psi)] \Big\} \\ &+ \left\{ \sum_{n=1}^N \left[\delta^{R-e} \operatorname{mdr} \{\Omega^2 [\phi_{X,j} ((a_2 - r\gamma_0) \sin \psi + (a_2 \gamma_0 + r) \cos \psi) + \phi_{Y,j} ((a_2 \gamma_0 + r) \sin \psi - (a_2 - r\gamma_0) \cos \psi) + \phi_{\theta Y,j} [(r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 + b_2) - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 (a_2 \beta_0 - r\beta_0) - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0) \sin \psi + (r(a_2 \beta_0 - b_2 \gamma_0) - b_2 (a_2 \gamma_0 + r) + a_2 ([r+e] \beta_0 - r^2 \beta_0$$

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+ I_{X} dr \{\Omega^{2} q^{i}_{E} \phi_{\theta Y,j} \sin \theta_{o} \cos \psi - \phi_{\theta X,j} \sin \theta_{o} \sin \psi) + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos^{2} \theta_{o} \cos \psi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos^{2} \theta_{o} \cos^{2} \theta_{o} \cos^{2} \theta_{o} \cos^{2} \theta_{o} \cos^{2} \phi)] + \Omega^{2} [\phi_{\theta Y,j} (\beta_{o} \cos^{2} \theta_{o} \cos^{2} \phi)]
                       -\frac{1}{2}\sin 2\theta_{0}\sin \psi) + \phi_{\theta X,j}(-\beta_{0}\cos^{2}\theta_{0}\sin \psi - \frac{1}{2}\sin 2\theta_{0}\cos \psi)]
                       + \operatorname{I}_{Y} \operatorname{dr} \{\Omega^{2} [\phi_{\theta Y,j} (-q'_{EO} \sin \theta_{o} - q'_{FO} \cos \theta_{o}) \cos \psi + \phi_{\theta X,j} (q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o}) + \operatorname{I}_{Y} \operatorname{dr} \{\Omega^{2} [\phi_{\theta Y,j} (-q'_{EO} \sin \theta_{o} - q'_{FO} \cos \theta_{o}) \cos \psi + \phi_{\theta X,j} (q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o}) + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o}) + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta_{o} + q'_{EO} \sin \theta
+q'_{FO}\cos\theta_{o})\sin\psi - \phi_{\theta Y,j}\beta_{o}\cos\psi + \phi_{\theta X,j}\beta_{o}\sin\psi]
             + I_{Z} dr \{\Omega^{2} q_{FO}^{\bullet}(\phi_{\theta Y,j} cos\theta_{o} cos\psi - \phi_{\theta X,j} cos\theta_{o} sin\psi) + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi) + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{2}[\phi_{\theta Y,j}(sin2\theta_{o} sin\psi)] + \Omega^{
               + \beta_0 \sin^2 \theta_0 \cos \psi) + \phi_{0X,j}(\frac{1}{2}\sin 2\theta_0 \cos \psi - \beta_0 \sin^2 \theta_0 \sin \psi)]\} \gamma
                                                         \left\{ \sum_{n=1}^{N} \sum_{i=1}^{NE} \left[ \delta^{R-e} \operatorname{mdr} \{\Omega^{2} [\phi_{X,j} (-\phi_{E,i} (\gamma_{o} \sin \psi - \cos \psi) - \nu_{1,i} \sin \psi + \cos \psi) - \nu_{1,i} \right] \right\} \right\}
-\phi_{F,i}\beta_{o}\sin\psi) + \phi_{Y,j}(\phi_{E,i}(\sin\psi + \gamma_{o}\cos\psi) + \nu_{l,i}\cos\psi + \phi_{F,i}\beta_{o}\cos\psi)
                         + \phi_{\theta Y,j}((\phi_{F,i}(a_2\gamma_0 + r + e - 2b_2\beta_0) - \phi_{E,i}b_2\gamma_0)\sin\psi + (-\phi_{F,i}(a_2 - r\gamma_0))
                         + \phi_{E,i}(b_2 + r\beta_0))\cos\psi) + \phi_{\theta X,j}((\phi_{F,i}(a_2 - r\gamma_0) - \phi_{E,i}(b_2 + r\beta_0))\sin\psi
                         + (\phi_{F,i}(a_2\gamma_0 + r + e - 2b_2\beta_0) - \phi_{E,i}b_2\gamma_0)\cos\psi) - \phi_{\theta Y,j}v_{1,i}b_2\sin\psi
   -\phi_{\theta X,j} v_{1,i} b_{2} cos \psi ] + I_{X} dr \{\Omega^{2} [\phi_{\theta Y,j} (-\sin\theta_{0} \sin\psi - (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0} \sin\theta_{0} + (\gamma_{0}                          -\beta_{o}\cos\theta_{o})\cos\psi)\phi^{\prime}_{E,i}+\phi_{\theta X,j}(-\sin\theta_{o}\cos\psi+(\gamma_{o}\sin\theta_{o}-\beta_{o}\cos\theta_{o})\sin\psi)\phi^{\prime}_{E,i}]\}
                         + \operatorname{I}_{Y} \mathrm{dr} \{\Omega^{2} \big[\phi_{\theta Y,j}(\phi_{E,j}^{\dagger} \sin\theta_{o} \sin\psi + (-q_{EO}^{\dagger} \sin2\theta_{o} - \beta_{o} \cos\theta_{o} - q_{FO}^{\dagger} \cos2\theta_{o} + q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO}^{\dagger} \sin\theta_{o} - q_{EO}^{\dagger} \cos\theta_{o} - q_{EO
                       + \gamma_0 \sin\theta_0 \cos\psi) + \phi_{F,i}^{\dagger} (-\cos\theta_0 \sin\psi + (-q_{F0}^{\dagger}\sin2\theta_0 - \beta_0 \sin\theta_0))
                         + q_{EO}^{\dagger}\cos 2\theta_{o} - \gamma_{o}\cos \theta_{o})\cos \psi)) + \phi_{\theta X,j}(\phi_{E,i}^{\dagger}(\sin \theta_{o}\cos \psi + (q_{EO}^{\dagger}\sin 2\theta_{o})))
   + \beta_0 \cos \theta_0 + q'_{F0} \cos 2\theta_0 - \gamma_0 \sin \theta_0 \sin \psi) + \phi'_{F,i} (- \cos \theta_0 \cos \psi + (- q'_{E0} \cos 2\theta_0
   + \beta_0 \sin\theta_0 + q'_{FO} \sin2\theta_0 + \gamma_0 \cos\theta_0 \sin\psi))] + I_Z dr \{\Omega^2 [\phi_{\theta Y,j} ((\cos\theta_0 \sin\psi))] + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \sin\psi)) + I_Z dr ((\cos\theta_0 \cos\psi)) + I_Z dr ((\cos\phi)) + I_Z dr ((\cos\phi)) 
                             + (-q_{EO}^{\dagger}\cos 2\theta_{o} + \gamma_{o}\cos \theta_{o} + \beta_{o}\sin \theta_{o})\cos \psi)\phi'_{F,i} + \phi'_{E,i}q'_{FO}\cos 2\theta_{o}\cos \psi)
                               + \phi_{0X,j}((\cos\theta_{0}\cos\psi + (q_{0}\cos2\theta_{0} - \gamma_{0}\cos\theta_{0} - \beta_{0}\sin\theta_{0})\sin\psi)\phi_{F,i}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    (37)
   -\phi'_{E,i}q'_{FO}\cos 2\theta_{o}\sin \psi)]]q_{T,i}
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\left\{\sum_{i=1}^{NA} \left[\frac{\text{Blade Pitch Equations}}{\delta^{R-e} \text{mdr}\{\phi_{X,i}((b_2 \gamma_0 + a_2 \beta_0) \sin \psi - b_2 \cos \psi) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}(-(b_2 \gamma_0) + \phi_{Y,i}
 + a_2 \beta_0 \cos \psi - b_2 \sin \psi + a_2 \phi_{Z,i} + \phi_{\theta Y,i} [((a_2^2 + b_2^2) \gamma_0 + a_2(r + e)) \sin \psi]
+ (-a_2(a_2 - r\gamma_0) - b_2(b_2 + r\beta_0))\cos\psi] + \phi_{\theta X,i}[(a_2(a_2 - r\gamma_0))]
 + b_2(b_2 + r\beta_0) sin\psi + ((a_2^2 + b_2^2)\gamma_0 + a_2(r + e))\cos\psi}
 + I_{X}dr\{q'_{EO}(\phi_{\theta Y,i}\cos\theta_{o}\sin\psi + \phi_{\theta X,i}\cos\theta_{o}\cos\psi)\} + I_{Y}dr\{\phi_{\theta Y,i}(-q'_{EO}\cos\theta_{o}\cos\psi)\}
 + q'_{FO}sin\theta_{o})sin\psi + \phi_{\theta X,i}( - q'_{EO}cos\theta_{o} + q'_{FO}sin\theta_{o})cos\psi + \phi_{\theta Y,i}(\gamma_{o}sin\psi
 -\cos\psi) + \phi_{\theta X,i}(\gamma_o^{'}\cos\psi + \sin\psi) + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\sin\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\cos\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\cos\psi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\sin\theta_o\phi)\} + I_Z dr\{q^*_{FO}(-\phi_{\theta Y,i}\cos\phi)\} + I_Z dr\{q^*
 -\phi_{\theta X,i} \sin\theta_{0} \cos\psi)\} \phi_{\theta}^{\frac{\pi}{q}} \left\{
 + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ \left( a_{2}^{2} + b_{2}^{2} \right) \right\} + I_{Y} dr \left\{ 1 \right\} \right] \phi_{\theta}^{2} \ddot{\theta}_{T}^{2} \right\} + \left\{ M_{1} L_{2}^{2} \phi_{\theta}^{2} R \ddot{\theta}_{T}^{2} \right\}
 + \left\{ \left[ \int_{0}^{R-e} m dr \{ (a_{2}^{2} + b_{2}^{2}) \gamma_{o} + a_{2}r \} + I_{\chi} dr \{ q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi} dr \{ - q'_{EO} cos\theta_{o} \} + I_{\chi
  + q'_{FO} sin\theta_{O} + \gamma_{O}
   + I_{Z}dr{ - q'_{FO}sin\theta_{O}} \phi_{\theta} \beta + \left\{-M_{1}L_{2}tan\delta_{3}\phi_{\theta}PR\beta
   + \left\{ \left[ \int_{0}^{R-e} m dr\{b_{2}r\} + I_{X} dr\{q'_{EO} sin\theta_{o}\} + I_{Y} dr\{-q'_{EO} sin\theta_{o} - q'_{FO} cos\theta_{o}\} \right] \right\}
   + I_{Z} dr \{q_{FO}^{*} cos\theta_{O}\} \right] \phi_{\theta} \ddot{\gamma} \left\{ + \right\} - M_{1} L_{2}^{2} tan\alpha_{1} \phi_{\theta PR} \ddot{\gamma} \left\}
   + \begin{cases} \sum_{i=1}^{NE} \left[ \int_{0}^{R-e} m dr \{ a_{2} \phi_{F,i} + b_{2} \phi_{E,i} \} + I_{X} dr \{ q'_{EO} \phi_{F,i}^{\dagger} \} + I_{Y} dr \{ - q'_{FO} \phi_{E,i}^{\dagger} \} \right] \end{cases}
       + I_{Z}dr{q'}<sub>FO</sub>\phi'_{E,i}} \phi_{\theta} = q_{T,i} + \sum_{i=1}^{NE} (-M_{1}L_{2})(\phi_{FPR,i})
      + [L_2^{\tan_2}/(R-e)]\phi_{ET,i})\phi_{\theta PR} \ddot{q}_{T,i}
    +\sum_{i=1}^{NA} \left[ s^{R-e} \operatorname{mod}_{2\Omega} \left[ \phi_{\theta Y,i} \left( a_{2} \left( a_{2} - r \gamma_{0} \right) \sin \psi + a_{2} \left( a_{2} \gamma_{0} + r + e - b_{2} \beta_{0} \right) \cos \psi \right] \right]
       + \phi_{\theta X,i}(-a_2(a_2\gamma_0 + r + e - b_2\beta_0)\sin\psi + a_2(a_2 - r\gamma_0)\cos\psi)] 10
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+ I_{X}dr\{2\Omega q^{\dagger}_{EO}[\phi_{\theta Y,i}\cos\theta_{o}\cos\psi - \phi_{\theta X,i}\cos\theta_{o}\sin\psi] + \Omega[\phi_{\theta Y,i}(-\cos2\theta_{o}\sin\psi)]
                                               - (\gamma_{0}\cos 2\theta_{0} - \beta_{0}\sin 2\theta_{0})\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi + (\gamma_{0}\cos 2\theta_{0}\cos \psi)) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\theta_{0}\cos \psi) + \phi_{\theta X,i}(-\cos 2\phi_{0}\cos \psi) + \phi_{\theta X,
                                                         -\beta_0 \sin 2\theta_0) \sin \psi) ] \} + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \}] + I_Y dr \{\Omega[\phi_{\theta Y,i}(-q'_{EO} \cos \theta_0) 2 \cos \phi_0) 2 \cos \psi \}
                                                      + \phi_{\theta X,i} (q^*_{EO} cos\theta_o - q^*_{FO} sin\theta_o) 2sin\psi + \phi_{\theta Y,i} (\gamma_o cos\psi + sin\psi) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_o sin\psi + \phi_{\theta X,i}) + \phi_{\theta X,i} (-\gamma_
                                                      + \cos\psi)]} + I_Z dr \{2\Omega q'_{FO}[-\phi_{\theta Y,i} \sin\theta_o \cos\psi + \phi_{\theta X,i} \sin\theta_o \sin\psi]
                                                         + \Omega[\phi_{\theta Y,i}(\cos 2\theta_0 \sin \psi + (\gamma_0 \cos 2\theta_0 - \beta_0 \sin 2\theta_0)\cos \psi) + \phi_{\theta X,i}(\cos 2\theta_0 \cos \psi)
                                               -\left(\gamma_{0}\cos 2\theta_{0}-\beta_{0}\sin 2\theta_{0})\sin \psi\right)\right]\}\right]\phi_{\theta}\dot{\bar{q}}_{i}\left\{+\right\}\left(2\zeta_{\theta}I_{T}\Omega+C_{1}L_{2}^{2}\phi_{\theta PR}^{2}\right)\dot{\theta}_{T}\left\{
                                               + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left[ -b_{2}(b_{2} + r\beta_{0}) \right] \right\} + I_{X} dr \left\{ -\Omega \cos 2\theta_{0} \right\} + I_{Y} dr \left\{ -\Omega \right\} \right\} \right\}
                                                         + I_{X}dr\{-\Omega \sin 2\theta_{0}\} + I_{Z}dr\{\Omega \sin 2\theta_{0}\} \phi_{\theta}\dot{\gamma} \left\{+\right\}-C_{1}L_{2}^{2}tan\alpha_{1}\phi_{\theta PR}\dot{\gamma}
              + \sum_{i=1}^{R} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0}) + \frac{1}{2} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0}) + \frac{1}{2} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} \right] + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0}) + \frac{1}{2} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} \right] + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0}) + \frac{1}{2} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} \right] + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0}) + \frac{1}{2} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} \right] + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0}) + \frac{1}{2} \left[ \int_{0}^{R-e_{i}} m dr \left\{ 2\Omega(-\phi_{F,i}b_{2}\beta_{0} + \phi_{E,i}a_{2}\beta_{0}) - 2\Omega\nu_{I,i}b_{2} \right\} \right] + I_{X}dr \left\{ \Omega[-\phi'_{E,i}\sin\theta_{0} + \phi_{E,i}a_{2}\beta_{0}] - 2\Omega\nu_{I,i}b_{2} \right] \right\} 
                                                           -\phi'_{F,i}\cos\theta_{o}]\} + I_{Y}dr\{\Omega[\phi'_{E,i}\sin\theta_{o} - \phi'_{F,i}\cos\theta_{o}]\} + I_{Z}dr\{\Omega[\phi'_{E,i}\sin\theta_{o}]\} + I_{Z}dr\{\Omega[\phi'_{E,i}\cos\theta_{o}]\} + I_{Z}d
                                                         + \phi'_{F,i}cos\theta_{o}]} \phi_{\theta}\dot{q}_{T,i} + \sum_{i=1}^{NL} (-C_{i}L_{2}(\phi_{FPR,i}))
                                                           + \left[L_2 \tan \alpha_1/(R-e)\right] \phi_{ET,i}) \phi_{\theta PR} \dot{q}_{T,i} + \left\{\int_0^{R-e} m dr \left\{\Omega^2 \left[e(a_2 \gamma_0 - b_2 \beta_0)\right]\right\} dr
                                                           -b_{2}(b_{2} + r\beta_{0}) + a_{2}^{2}]\} + I_{X}dr\{-\Omega^{2}cos2\theta_{0}\} + I_{Z}dr\{\Omega^{2}cos2\theta_{0}\} \Big]\phi_{\theta}^{2}\theta_{T} 
                                                           + \left\{ \left( \left\{ \mathbf{K}^{\mathbf{R}-\mathbf{e}} \mathbf{K} \phi_{\theta}^{2} \right\} \right) \mathbf{\theta}_{\mathbf{T}} \right\} + \left\{ \mathbf{K}_{1} \mathbf{L}_{2}^{2} \phi_{\theta}^{2} \mathbf{e}_{\mathbf{P}} \mathbf{R}^{\theta} \mathbf{T} \right\}
                                                           + \left. \left\{ \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{2} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{2} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{2} \beta_{0} \right) \right] \right\} \right. \\ + \left. \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right\} \right. \\ + \left. \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right\} \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right. \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \right] \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( b_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} - 2 a_{2}^{\gamma} \beta_{0} \right) \right] \right] \\ + \left[ \int_{0}^{R-e} m dr \left\{ \Omega^{2} \left[ a_{2}^{\gamma} \left( a_{2}^{\gamma} \gamma_{0} + r + e \right) - b_{2}^{\gamma} \left( a_{2}^{\gamma}
                                                             - \gamma_{o} cos2\theta_{o} ) \} + I_{Y} dr \{\Omega^{2} (- q'_{EO} cos\theta_{o} + q'_{FO} sin\theta_{o})\} + I_{Z} dr \{\Omega^{2} [- q'_{FO} sin\theta_{o}]\} + I
+ \gamma_{\mathbf{0}} \cos 2\theta_{\mathbf{0}} \right] \right] \phi_{\theta} \beta \left\{ + \right\} - K_{1} \frac{L^{2}}{2} \tan \delta_{3} \phi_{\theta} PR \beta \left\{ + \right\} \left[ \left\{ 8^{R-e} \operatorname{mdr} \left\{ \Omega^{2} \left[ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right] \right\} \right] \right] \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{ - \left( a_{2}^{2} + b_{2}^{2} \right) \beta_{\mathbf{0}}^{2} \right\} \left\{
                                                                + eb_{2}] + I_{X}dr\{-\Omega^{2}\beta_{0}\cos 2\theta_{0}\} + I_{Z}dr\{\Omega^{2}\beta_{0}\cos 2\theta_{0}\} \Big] \phi_{\theta} \gamma  { 11
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$$+ \left\{ - K_{1}^{L_{2}^{2} \tan \alpha_{1}^{2} \phi_{PR}^{\gamma}} \right\} + \left\{ \sum_{i=1}^{NE} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2}} \left[\int_{0}^{R-e_{i}^{2} - e_{i}^{2} - e$$

Blade Rigid-Body Flapping Equations

$$\begin{cases} \sum_{k=1}^{N} \left[\int_{0}^{R-e} m dr \{ \phi_{X,i} (b_{2} + r\beta_{0}) \sin \psi - \phi_{Y,i} (b_{2} + r\beta_{0}) \cos \psi + \phi_{Z,i} (r + a_{2}\gamma_{0} - b_{2}\beta_{0}) + \phi_{0Y,i} [(e(a_{2}\gamma_{0} - b_{2}\beta_{0}) + r(r + e + 2a_{2}\gamma_{0}) + b_{2}^{2}) \sin \psi + (-a_{2}(a_{2}\gamma_{0} - b_{2}\beta_{0}) - r(a_{2} - r\gamma_{0})) \cos \psi] + \phi_{0X,i} [(a_{2}(a_{2}\gamma_{0} - b_{2}\beta_{0}) + r(a_{2} - r\gamma_{0})) \sin \psi + (e(a_{2}\gamma_{0} - b_{2}\beta_{0}) + r(r + e + 2a_{2}\gamma_{0}) + b_{2}^{2}) \cos \psi] \} + I_{X} dr \{q^{i}_{EO}(-\phi_{0Y,i} \cos \theta_{0} \cos \psi + \phi_{0X,i} (\cos \theta_{0} \sin \psi) + \phi_{0Y,i} (\cos \theta_{0} \cos \psi + (\gamma_{0} \cos \theta_{0} \cos \psi) + (\gamma_{0} \cos \theta_{0} \cos \psi) + (\gamma_{0} \cos \theta_{0} - \frac{1}{2}\beta_{0} \sin \theta_{0}) \cos \psi) + \phi_{0X,i} (\cos \theta_{0} \cos \psi - (\gamma_{0} \cos \theta_{0} - \frac{1}{2}\beta_{0} \sin \theta_{0}) \sin \psi)) \} + I_{Y} dr \{\phi_{0Y,i} (q^{i}_{EO} \cos \theta_{0} - q^{i}_{FO} \sin \theta_{0} - \gamma_{0}) \cos \psi + \phi_{0X,i} (-q^{i}_{EO} \cos \theta_{0} + q^{i}_{FO} \sin \theta_{0} + \gamma_{0}) \sin \psi) + I_{Z} dr \{q^{i}_{FO} (\phi_{0Y,i} \sin \theta_{0} \cos \psi) + \phi_{0X,i} \sin \theta_{0} \sin \psi) + \phi_{0X,i} (\sin \theta_{0} - \gamma_{0}) \sin \psi) + \phi_{0X,i} (\sin \theta_{0} \cos \psi) + \phi_{0X,i} (\sin \theta_{0} \cos \psi) + (\gamma_{0} \sin \theta_{0} + \gamma_{0}) \sin \psi) + \phi_{0X,i} (\sin \theta_{0} \cos \psi) + (\gamma_{0} \sin \theta_{0} + \gamma_{0}) \sin \psi))] \frac{\pi}{q_{i}} \} + \begin{cases} \int_{0}^{R-e} m dr \{((a_{2}^{2} + b_{2}^{2})\gamma_{0} + a_{2}r)\} + I_{X} dr \{q^{i}_{EO} \cos \theta_{0}\} + I_{Y} dr \{(-q^{i}_{EO} \cos \theta_{0}) + q^{i}_{FO} \sin \theta_{0} + \gamma_{0})\} + I_{X} dr \{\phi_{0}^{i}_{EO} \cos \theta_{0}\} + I_{X} d$$

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-b_2^{\beta_0} - b_2^{2} \sin \psi + (a_2(a_2^{\gamma_0} - b_2^{\beta_0}) - r^2 \gamma_0) \cos \psi)]
         + I_X dr(2\Omega q^* E_0)(\phi_{\theta Y,i} cos\theta_0 sin\psi + \phi_{\theta X,i} cos\theta_0 cos\psi)
         + \Omega \left[\phi_{\theta Y,i}(\cos \psi - 2(\gamma_0 \cos^2 \theta_0 - \frac{1}{2}\beta_0 \sin 2\theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\sin \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \theta_0) \sin^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \sin^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X,i}(-\cos \psi - 2(\gamma_0 \cos^2 \phi_0) \cos^2 \psi) + \phi_{\theta X
         - \frac{1}{2} \beta_0 \sin 2\theta_0) \cos \psi) ] \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{FO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \sin \theta_0) 2 \sin \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0 + q'_{EO} \cos \theta_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \theta_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \theta_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \theta_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \theta_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \theta_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \theta_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \theta_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} \} + I_Y dr \{ \Omega [\phi_{\theta Y,i} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{EO} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{EO} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{EO} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos \phi_0) 2 \cos \psi \} + I_Y dr \{ \Omega [\phi_{EO} (- q'_{EO} \cos \phi_0) + q'_{EO} \cos 
             + \phi_{\theta X,i}(- q_{EO}^{\circ}\cos\theta_{o} + q_{FO}^{\circ}\sin\theta_{o})2cos\psi
                 + \phi_{\theta Y,i}(2\gamma_0 \sin \psi - \cos \psi) + \phi_{\theta X,i}(2\gamma_0 \cos \psi + \sin \psi)] + I_Z dr\{2\Omega q'_{FO}[
-\phi_{\theta Y,i} \sin \theta_{o} \sin \psi -\phi_{\theta X,i} \sin \theta_{o} \cos \psi + \Omega [\phi_{\theta Y,i} (\cos \psi - (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o} + (2\gamma_{o} \sin^{2} \theta_{o
             +\beta_0 \sin 2\theta_0 \sin \psi) + \phi_{\theta X,i} (-\sin \psi - (2\gamma_0 \sin^2 \theta_0 + \beta_0 \sin 2\theta_0) \cos \psi)] \} \Big| \dot{\overline{q}}_i \Big|
               + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega b_{2}(b_{2} + r\beta_{0}) \right\} + I_{X} dr \left\{ \Omega \cos 2\theta_{0} \right\} + I_{Y} dr \left\{ \Omega \right\} + I_{Z} dr \left\{ - \Omega \cos 2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\}
               + \left\{ - C_{1}^{L_{2}^{2}} \tan \delta_{3} \phi_{\theta PR} \dot{\theta}_{T} \right\} + \left\{ C_{1}^{L_{2}^{2}} \tan^{2} \delta_{3} \dot{\beta} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right\} \right] \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right\} \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right\} \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right\} \right] \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} \right\} + \left\{ \left[ \int_{0}^{R-e} m dr \left\{ 2\Omega \left( b_{2}^{\alpha} (a_{2}^{\gamma} \gamma_{0} + r) \right) \right] \right\} \right\} \right\} 
                 + r^2\beta_0)} + I_X dr\{\Omega(2q_{EO}^*\sin\theta_0 + \beta_0 - \gamma_0\sin2\theta_0)\} + I_Y dr\{\Omega(-2q_{EO}^*\sin\theta_0)\}
               -2q'_{FO}\cos\theta_{o}-\beta_{o})\}+I_{Z}dr\{\Omega(2q'_{FO}\cos\theta_{o}+\gamma_{o}\sin2\theta_{o}+\beta_{o})\}\Big]\dot{\gamma}\Big\{
   + \left\{C_1L_2^2\tan\delta_3\tan\alpha_1\dot{\gamma}\right\} + \left\{\sum_{i=1}^{NE}\left[\int_0^{R-e}mdr\left\{2\Omega\left[\phi_{E,i}\left(b_2+r\beta_0\right)\right]\right\}\right]\right\}
                 + I_{X}dr\{\Omega[\phi'_{E,i}(q'_{EO}sin2\theta_{o} + \beta_{o}cos\theta_{o} - \gamma_{o}sin\theta_{o}) + \phi'_{F,i}(q'_{EO} + \beta_{o}sin\theta_{o})\}
                 -\gamma_{o}\cos\theta_{o})]\} + I_{Y}dr\{\Omega[\phi'_{E,i}(-q'_{EO}\sin2\theta_{o}-2q'_{FO}\cos^{2}\theta_{o}+\gamma_{o}\sin\theta_{o}-\beta_{o}\cos\theta_{o})\}
                 + \phi'_{F,i}(q'_{EO}\cos 2\theta_o - q'_{FO}\sin 2\theta_o - \gamma_o\cos\theta_o - \beta_o\sin\theta_o)]
                 + I_{\mathbf{Z}}^{\mathrm{dr}}\{\Omega[\phi'_{\mathbf{E},\mathbf{i}}(2q'_{\mathbf{F}0}\cos^2\theta_0 + \gamma_0\sin\theta_0 + \beta_0\cos\theta_0) + \phi'_{\mathbf{F},\mathbf{i}}(q'_{\mathbf{F}0}\sin2\theta_0 + \gamma_0\cos\theta_0)\}
                 + \beta_0 \sin \theta_0)]]d_{T,i}+\left\{\sum_{i=1}^{NE} (c_1 L_2 \tan \delta_3 (\phi_{FPR,i} + [L_2 \tan \alpha_1/(R-e)]\phi_{ET,i}))\dot{q}_{T,i}\right\}
                    +\left\{\sum_{i=1}^{NA}\left[\left(\frac{B-e}{2\pi}\right)\left(\frac{1}{2}\left(\frac{1}{2}\right)\right)\left(\frac{1}{2}\left(\frac{1}{2}\right)\right)\cos\psi\right] + \left(\frac{1}{2}\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}
                                                                             \int_{0}^{\infty} \left[ \int_{0}^{\infty} dr \left\{ \Omega^{2} \left[ a_{2} \alpha_{0} + r + e \right] - b_{2} \left( b_{2} \alpha_{0} - 2 a_{2} \beta_{0} \right) \right] \right\} + I_{X} dr \left\{ \Omega^{2} \left[ q'_{EO} \cos \theta_{0} \right] \right\} 
                   -\gamma_{o}\cos2\theta_{o}+\beta_{o}\sin2\theta_{o}]\}+I_{Y}\mathrm{dr}\{\Omega^{2}[-q'_{EO}\cos\theta_{o}-q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]\}+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}\{\Omega^{2}[q'_{FO}\sin\theta_{o}]]+I_{Z}\mathrm{dr}[Q'_{FO}\sin\theta_{o}]
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$$\left\{ + \gamma_{0}\cos 2\theta_{0} - \beta_{0}\sin 2\theta_{0} \right\} \right\} \phi_{0} \eta_{1} + \left\{ - K_{1}L_{2}^{2}\tan \delta_{3}\phi_{0}R\theta_{T} \right\}$$

$$+ \left\{ \left[g^{R-e} \inf \left\{ \Omega^{2} \left[e(\mathbf{a}_{2}\gamma_{0} - \mathbf{b}_{2}\beta_{0}) + r(r+e) - 4r\beta_{0}\mathbf{b}_{2} + 2\mathbf{a}_{2}r\gamma_{0} - \mathbf{b}_{2}^{2} \right] \right\} \right\}$$

$$+ I_{X} dr \left\{ \Omega^{2}\sin^{2}\theta_{0} \right\} + I_{Y} dr \left\{ - \Omega^{2} \right\} + I_{Z} dr \left\{ \Omega^{2}\cos^{2}\theta_{0} \right\} \right] \beta \right\} + \left\{ K_{1}L_{2}^{2}\tan^{2}\delta_{3}\beta \right\}$$

$$+ \left\{ K_{\beta}\beta \right\} + \left\{ \left[g^{R-e} \inf \left\{ \Omega^{2} \left[\mathbf{b}_{2}(\mathbf{a}_{2} - r\gamma_{0}) + \mathbf{a}_{2}\beta_{0}(2r+e) \right] \right\} + I_{X} dr \left\{ - \frac{1}{2}\Omega^{2}\sin 2\theta_{0} \right\} + I_{Z} dr \left\{ \frac{1}{2}\Omega^{2}\sin 2\theta_{0} \right\} \right\} \gamma \right\} + \left\{ K_{1}L_{2}^{2}\tan \delta_{3}\tan \alpha_{1}\gamma \right\}$$

$$+ \left\{ \sum_{i=1}^{NE} \left[g^{R-e} \inf \left\{ \Omega^{2} \left[- \phi_{E,i} \mathbf{b}_{2}\gamma_{0} + \phi_{F,i} (\mathbf{a}_{2}\gamma_{0} + r+e + 2\mathbf{b}_{2}\beta_{0}) - \mathbf{v}_{1,i} \mathbf{b}_{2} \right] \right\} \right\}$$

$$+ I_{X} dr \left\{ - \Omega^{2}\phi'_{E,i} \sin \theta_{0} \right\} + I_{Y} dr \left\{ \Omega^{2} \left[\phi'_{E,i} \sin \theta_{0} + \phi'_{F,i} \cos \theta_{0} \right] \right\}$$

$$+ I_{Z} dr \left\{ - \Omega^{2} \left[\phi'_{F,i} \cos \theta_{0} \right] \right\} q_{T,i} \right\} + \left\{ \sum_{i=1}^{NE} \left(K_{1} L_{2} \tan \delta_{3} (\phi_{FPR,i} + \mathbf{b}_{1}) \right) q_{T,i} \right\}$$

$$+ \left[L_{2} \tan \alpha_{1} / (R-e) \right] \phi_{ET,i} \right\} \eta_{T,i}$$

$$+ \left[L_{2} \tan \alpha_{1} / (R-e) \right] \phi_{ET,i} \right\} \eta_{T,i}$$

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\left\{\sum_{i=1}^{NA}\left[s^{R-e}_{x,i}(-(a_2-r\gamma_0)\sin\psi-(a_2\gamma_0+r)\cos\psi)+\phi_{Y,i}(-(a_2\gamma_0+r)\sin\psi\right]\right\}
                              + (a_2 - r\gamma_0)\cos\psi) + \phi_{Z,i}a_2\beta_0 + \phi_{\theta Y,i}(([e\beta_0 - b_2](a_2 - r\gamma_0))\sin\psi
                              + (-b_2(a_2\gamma_0 + r) - (a_2^2 + r^2)\beta_0) \cos \psi) + \phi_{\theta X,i}((b_2(a_2\gamma_0 + r) + (a_2^2 + r^2)\beta_0)) \cos \psi)
                                  + r^{2})\beta_{0})\sin\psi + ([e\beta_{0} - b_{2}](a_{2} - r\gamma_{0}))\cos\psi) \} + I_{X}dr\{q'_{EO}(-\phi_{\theta Y,i}\sin\theta_{0}\cos\psi)\} + I_{X}dr\{q'_{EO}(-\phi_{\theta Y,i}\cos\psi)\} + I_{X}dr\{q'_{EO}(-\phi_{\theta Y,i}\cos
                                  + \phi_{\theta X,i} \sin^{\theta} \cos^{\sin \psi}) + \phi_{\theta Y,i} (\sin^{2} \theta_{0} \sin \psi + (\cos^{2} \theta_{0} \sin^{2} \theta_{0} - \beta_{0} \sin^{2} \theta_{0}) \cos \psi)
                                    +\phi_{\theta X,i}({}^{1}_{z\sin 2\theta_{0}\cos \psi}-({}^{1}_{z\gamma_{0}\sin 2\theta_{0}}-\beta_{0}\sin^{2}\theta_{0})\sin \psi))+I_{\chi}dr\{\phi_{\theta Y,i}({}^{q}_{EO}\sin^{2}\theta_{0})\sin \psi)\}+I_{\chi}dr\{\phi_{\theta Y,i}({}^{q}_{EO}\sin^{
                                       + q'_{FO}^{\cos\theta}_{o}^{\cos\psi} + \phi_{\theta X,i}^{(-q'_{EO}\sin\theta_{o} - q'_{FO}^{\cos\theta_{o}})\sin\psi} + I_{Z}^{dr}_{q'_{FO}}^{(-q'_{EO}\sin\theta_{o} - q'_{FO}^{\cos\theta_{o}})\sin\psi}
                                         -\phi_{\theta Y,i} \cos \theta_{o} \cos \psi + \phi_{\theta X,i} \cos \theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi - (\frac{1}{2} \gamma_{o} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \sin 2\theta_{o} \sin \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_{o} \cos \psi) + \phi_{\theta Y,i} (-\frac{1}{2} \cos \theta_
                                         + \beta_{0}\cos^{2}\theta_{0})\cos\psi) + \phi_{0X,i}(-\frac{1}{2}\sin^{2}\theta_{0}\cos\psi + (\frac{1}{2}\gamma_{0}\sin^{2}\theta_{0} + \beta_{0}\cos^{2}\theta_{0})\sin\psi))]\frac{\pi}{q_{i}} 
                                           + \left\{ \left[ \left\{ e^{R-e} dr \left\{ b_{2}r \right\} + I_{X} dr \left\{ q'_{EO} sin\theta_{0} \right\} + I_{Y} dr \left\{ -q'_{EO} sin\theta_{0} - q'_{FO} cos\theta_{0} \right\} \right\} \right\}
                                           + I_{Z}^{dr\{q'}_{FO}^{cos\theta_{o}\}} + \frac{\ddot{\theta}_{T}}{4} + - M_{1}^{L_{2}^{2}}^{2} \tan q_{\theta PR}^{\theta} + \frac{1}{2} \left\{ + \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left\{ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac{1}{2} \left[ - \frac
                                             -r\gamma_{0}) + I_{X}dr\{\frac{1}{2}sin2\theta_{0}\} + I_{Z}dr\{-\frac{1}{2}sin2\theta_{0}\} \beta + M_{1}L_{2}^{2}tan\delta_{3}tan\alpha_{1} \beta
                                               + \left\{ \left[ \int_0^{R-e_{\text{mdr}} \left\{ a_2^2 + r^2 \right\}} + I_{X} dr \left\{ \sin^2 \theta_0 \right\} + I_{Z} dr \left\{ \cos^2 \theta_0 \right\} \right] \ddot{Y} \right\}
                 + \left\{ M_{1}L_{2}^{2}\tan^{2}\alpha_{1}^{2}\Upsilon \right\} + \left\{ \sum_{i=1}^{NE} \left[ \delta^{R-e} m dr \{ \phi_{E,i}r - a_{2}v_{1,i} \} + I_{X} dr \{ \phi'_{F,i} sin\theta_{0} \} \right] \right\}
                                               + I_{Z}^{dr\{\phi'_{E,i}\cos\theta_{o}\}} Q_{T,i} + \left\{\sum_{i=1}^{NE}(M_{1}L_{2}^{tana}(\phi_{FPR,i}^{tana}))\right\}
                                + (r + e)a_2\beta_0\cos\psi + \phi_{\theta X,i}(-(r + e)a_2\beta_0\sin\psi + a_2^2\beta_0\cos\psi)]
                                                        + I_{X} dr \{\Omega [-\phi_{\theta Y,i}^{3} \beta_{0} \cos 2\theta_{0} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi]\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos 2\theta_{0} \cos \psi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \sin \psi - \phi_{\theta X,i} \beta_{0} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y} dr \{\Omega \beta_{0} (\phi_{\theta Y,i} \cos \phi)\} + I_{Y}
                                                          + \phi_{\theta X,i} \cos \psi) \} + I_{Z} dr \{ \Omega \beta_{o} (\phi_{\theta Y,i} \cos 2\theta_{o} \sin \psi + \phi_{\theta X,i} \cos 2\theta_{o} \cos \psi) \} ] \bar{q}_{i} 
                                                        + \left\{ \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{Z} dr \left\{ -\Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{Z} dr \left\{ -\Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{Z} dr \left\{ -\Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{Z} dr \left\{ -\Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{Z} dr \left\{ -\Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right\} / \left[ \left\{ \frac{R-e_{mdr} \left\{ -2\Omega a_{2} \left( b_{2} + r\beta_{0} \right) \right\} + I_{X} dr \left\{ \Omega sin2\theta_{0} \right\} \right\} \right] \phi_{\theta} \dot{\theta}_{T} \right]
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$$+ \begin{cases} - c_1 L_2^2 tan a_1 \phi_6 \delta_T \\ + \begin{cases} \int_0^{R-e} dt f_e^* - 2\Omega(r^2 \beta_0 + b_2(a_2 \gamma_0 + r)) + I_X dr \{\Omega(-2q_{-0}^* sin \theta_0 + \gamma_0 sin 2\theta_0 - \beta_0) \} \\ + \int_0^{R-e} f_0 + I_X dr \{\Omega \beta_0 \} + I_Z dr \{\Omega(-2q_{-0}^* cos \theta_0 - \gamma_0 sin 2\theta_0 - \beta_0) \} \\ + \int_0^{R-e} f_0 + I_X dr \{\Omega \beta_0 \} + I_Z dr \{\Omega(-2q_{-0}^* cos \theta_0 - \gamma_0 sin 2\theta_0 - \beta_0) \} \\ + \int_0^{R-e} f_0 f_0 + I_X dr \{\Omega \beta_0 \} +$$

Blade Bending Equations

$$\begin{cases} \sum_{i=1}^{N} \left[e^{-i\theta_i} dr_{\phi_{X,i}} [\phi_{E,j} (\gamma_0 \sin\psi - \cos\psi) + \nu_{1,j} \sin\psi + \phi_{F,j} \beta_0 \sin\psi] \right] \\ + \phi_{Y,i} [\phi_{E,j} (-\gamma_0 \cos\psi - \sin\psi) - \nu_{1,j} \cos\psi - \phi_{F,j} \beta_0 \cos\psi] + \phi_{Z,i} \phi_{F,j} \right] \\ + \phi_{QY,i} [(\phi_{E,j} b_2 \gamma_0 + \phi_{F,j} (a_2 \gamma_0 + r + e)) \sin\psi + (-\phi_{F,j} (a_2 - r \gamma_0)) \\ - \phi_{E,j} (b_2 + r \beta_0)) \cos\psi] + \phi_{QX,i} [(\phi_{F,j} (a_2 - r \gamma_0) + \phi_{E,j} (b_2 + r \beta_0)) \sin\psi] \\ + (\phi_{E,j} b_2 \gamma_0 + \phi_{F,j} (a_2 \gamma_0 + r + e)) \cos\psi] + \phi_{QY,i} b_2 \gamma_{1,j} \sin\psi + \phi_{QX,i} b_2 \gamma_{1,j} \cos\psi] \\ + I_X dr_{QY,i} [\phi_{QY,i} (\cos\theta_0 \sin\psi + (\gamma_0 \cos\theta_0 - \theta_0 \sin\theta_0 - q'_{E0}) \cos\psi)] \\ + V_{QX,i} (\cos\theta_0 \cos\psi - (\gamma_0 \cos\theta_0 - \theta_0 \sin\theta_0 - q'_{E0}) \sin\psi]] \\ + I_Y dr_{QY,i} [\phi_{QY,i} q'_{F0} \cos\psi - \phi_{QX,i} q'_{F0} \sin\psi]] + I_Z dr_{QY,i} [\phi_{QY,i} (-\sin\theta_0 \sin\psi)] \\ + I_Y dr_{QY,i} [\phi_{QY,i} q'_{F0} \cos\psi - \phi_{QX,i} q'_{F0} \sin\psi]] + I_Z dr_{QY,i} [\phi_{QY,i} (-\sin\theta_0 \sin\psi)] \\ + V_{QY,i} [\phi_{QY,i} q'_{F0} \cos\psi] + \phi_{QX,i} (-\sin\theta_0 \cos\psi + (\gamma_0 \sin\theta_0 + \theta_0 \cos\theta_0 + q'_{F0}) \sin\psi]] \\ + I_Y dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{E,j}] + V_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{F,j}] + I_X dr_{QY,i} \phi'_{F,j}] \\ + I_Y dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{E,j}] + I_Z dr_{QY,i} \phi'_{F,j}] \\ + I_Y dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{E,j}] + I_Z dr_{QY,i} \phi'_{F,j}] \\ + I_Y dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{E,j}] + I_Z dr_{QY,i} \phi'_{F0} q'_{F0}] \\ + V_{Z} dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{F,j}] + I_Z dr_{QY,i} \phi'_{F0} q'_{F0}] \\ + V_{Z} dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{F,j}] + I_Z dr_{QY,i} \phi'_{F,j} q'_{F0} q'_{F0}] \\ + V_{Z} dr_{QY,i} [\phi_{QY,i} q'_{F0} \phi'_{F,j}] + I_Z dr_{QY,i} \phi'_{F,j} q'_{F,j} q'_{F,j} q'_{F,j} q'_{F0}$$

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-\beta_{0}\sin\theta_{0})\sin\psi) + \phi_{\theta X,i}(-\cos\theta_{0}\sin\psi - (\gamma_{0}\cos\theta_{0} - q'_{EO} - \beta_{0}\sin\theta_{0})\cos\psi))
  + \phi'_{E,j}(\phi_{\theta',k}(-\sin\theta_0\cos\psi + (\gamma_0\sin\theta_0 - \beta_0\cos\theta_0 - q'_{EO}\sin2\theta_0)\sin\psi)
+\phi_{\theta X,i}(\sin\theta_{o}\sin\psi + (\gamma_{o}\sin\theta_{o} - \beta_{o}\cos\theta_{o} - q'_{EO}\sin2\theta_{o})\cos\psi))]
            + I_{Y}dr\{\Omega[\phi'_{E,j}(\phi_{\theta Y,i}(\sin\theta_{o}\cos\psi + (q'_{EO}\sin2\theta_{o} - 2q'_{FO}\sin^{2}\theta_{o}
+\beta_0\cos\theta_0-\gamma_0\sin\theta_0)\sin\psi)+\phi_{\theta X,i}(-\sin\theta_0\sin\psi+(q'_{EO}\sin2\theta_0-2q'_{FO}\sin^2\theta_0))
            +\beta_0 \cos\theta_0 - \gamma_0 \sin\theta_0) \cos\psi)) + \phi_{F,j}^{\dagger}(\phi_{\theta Y,i}(-\cos\theta_0 \cos\psi + (-q_{EO}^{\dagger}\cos2\theta_0 \cos\psi))) + \phi_{EO}^{\dagger}(-\cos\theta_0 \cos\psi) + (-q_{EO}^{\dagger}\cos2\theta_0 \cos\psi))
        + q'_{FO} \sin 2\theta_o + \beta_o \sin \theta_o + \gamma_o \cos \theta_o) \sin \psi) + \phi_{\theta X,i} (\cos \theta_o \sin \psi + (- q'_{EO} \cos 2\theta_o)) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin \psi + (- q'_{EO} \cos 2\theta_o) \sin 
      + q'_{FO} \sin 2\theta_{o} + \beta_{o} \sin \theta_{o} + \gamma_{o} \cos \theta_{o}) \cos \psi))]\} + I_{Z} dr \{\Omega[\phi'_{F,j}(\phi_{\theta Y,i}(\cos \theta_{o} \cos \psi)))\} + I_{Z} dr \{\Omega[\phi'_{F,j}(\phi_{\theta Y,i}(\cos \theta_{o} \cos \psi)))]\}
           -(q'_{FO}^{\sin 2\theta}_{o} - q'_{EO}^{\cos 2\theta}_{o} + \gamma_{o}^{\cos \theta}_{o} + \beta_{o}^{\sin \theta}_{o})^{\sin \psi}) + \phi_{\theta X,i}(-\cos \theta_{o}^{\sin \psi})
      -(q'_{FO}\sin 2\theta_{o}-q'_{EO}\cos 2\theta_{o}+\gamma \cos \theta_{o}+\beta_{o}\sin \theta_{o})\cos \psi))+\phi'_{E,j}((-\sin \theta_{o}\cos \psi))
              + (2q'_{FO}\sin^2\theta_o + \gamma_o\sin\theta_o + \beta_o\cos\theta_o)\sin\psi)\phi_{\thetaY,i} + \phi_{\thetaX,i}(\sin\theta_o\sin\psi)\phi_{\thetaY,i}
              + \left(2q'_{FO}\sin^2\theta_o + \gamma_o\sin\theta_o + \beta_o\cos\theta_o)\cos\psi\right)\right]\right] = \frac{1}{q_1} \left\{ + \left\{ \left[\int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi\}\right]\right\} \right\} = \frac{1}{q_1} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi\}\right\} \right\} = \frac{1}{q_1} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} \left\{ + \left\{ \int_0^{R-e} mdr\{2\Omega(\phi_{F,j}b_2\beta_o)\cos\psi}\right\} \right\} = \frac{1}{q_2} 
              -\phi_{E,j}a_2\beta_0) + 2\Omega\nu_{1,j}b_2\} + I_{X}dr\{\Omega(\phi'_{F,j}cos\theta_0 + \phi'_{E,j}sin\theta_0)\}
              + I_{Y}dr\{\Omega(-\phi'_{E,j}sin\theta_{o}+\phi'_{F,j}cos\theta_{o})\} + I_{Z}dr\{\Omega(-\phi'_{E,j}sin\theta_{o}+\phi'_{F,j}cos\theta_{o})\}
              -\phi'_{E,j}\sin\theta_{o}-\phi'_{F,j}\cos\theta_{o})\}\Big]\phi_{\theta}\dot{\theta}_{T}\Big\} + \Big\}-C_{1}L_{2}\phi_{\theta PR}(\phi_{FPR,j}
              + \left[L_{2}^{\text{tana}}/(R-e)\right]\phi_{\text{ET,j}} \dot{\theta}_{\text{T}} + \left\{\left[\delta^{R-e}_{\text{mdr}}\left(-2\Omega\phi_{E,j}\left(b_{2}+r\beta_{0}\right)\right)\right\}\right\}
              + I_{X} dr \{\Omega[\phi'_{F,j}(\gamma_{o} cos\theta_{o} - \beta_{o} sin\theta_{o} - q'_{EO}) + \phi'_{E,j}(\gamma_{o} sin\theta_{o} - \beta_{o} cos\theta_{o} + \beta_{o} cos\theta_{o})\}
              -q'_{EO}sin2\theta_{o})]\} + I_{Y}dr\{\Omega[\phi'_{E,j}(q'_{EO}sin2\theta_{o} + 2q'_{FO}cos^{2}\theta_{o} - \gamma_{o}sin\theta_{o}
               + \beta_0 \cos \theta_0) + \beta_{F,j}(- q'_{E0}\cos 2\theta_0 + q'_{F0}\sin 2\theta_0 + \gamma_0 \cos \theta_0+ \beta_0 \sin \theta_0)]
          + I_Z dr \{ \Omega [\phi'_{E,j}(-2q'_{FO}cos^2\theta_o - \gamma_o sin\theta_o - \beta_o cos\theta_o) + \phi'_{F,j}(-q'_{FO}sin2\theta_o) \}
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+ q'_{EO}^{\cos 2\theta_0} - \gamma_0 \cos \theta_0 - \beta_0 \sin \theta_0 } \delta + C_1 L_2 \tan \delta_3 (\phi_{PPR,j})
+ \left[L_{2}\tan\alpha_{1}/(R-e)\right]\phi_{ET,j} \beta + \left\{\left[\int_{0}^{R-e} mdr\left\{2\Omega\left(a_{2}\phi_{E,j} + r\beta_{0}\phi_{F,j} + v_{1,j}r\right)\right\}\right\}
+ I_X dr \{\Omega[\phi'_{F,j}\beta_0 cos\theta_0 - \phi'_{E,j}(\beta_0 sin\theta_0 + 2q'_{EO} sin^2\theta_0)]\}
      + I_Y dr \{\Omega[\phi'_{E,j}(2q'_{EO}sin^2\theta_o + q'_{FO}sin^2\theta_o + \beta_o sin\theta_o) + \phi'_{F,j}(-q'_{EO}sin^2\theta_o)\}
      -2q'_{FO}\cos^2\theta_o -\beta_o\cos\theta_o)]\} + I_Z dr\{\Omega[\phi'_{E,j}(-q'_{FO}\sin2\theta_o -\beta_o\sin\theta_o)]\}
      + \phi_{F,j}^{\dagger}(2q_{FO}^{\dagger}\cos^2\theta_0 + q_{EO}^{\dagger}\sin^2\theta_0 + \beta_0\cos\theta_0)]
     + \left[L_{2}\tan\alpha_{1}/(R-e)\right]\phi_{ET,j} \uparrow \left\{\sum_{i=1}^{NE}\left[\int_{0}^{R-e}mdr\left\{2\Omega\left[\nu_{1,j}\phi_{E,i}-\nu_{1,i}\phi_{E,j}\right]\right]\right\}\right\}
      + \beta_0(\phi_{F,j}\phi_{E,i} - \phi_{F,i}\phi_{E,j})] + I_X dr \{\Omega(\beta_0)
     + q'<sub>EO</sub>sin<sup>6</sup>o)(¢'<sub>F,j</sub>¢'<sub>E,i</sub> - ¢'<sub>E,j</sub>¢'<sub>F,i</sub>)}
      + I_{Y}dr\{\Omega(q_{EO}^{\dagger}\sin\theta_{o} + 2q_{FO}^{\dagger}\cos\theta_{o} + \beta_{o})(\phi_{E,j}^{\dagger}\phi_{F,i}^{\dagger} - \phi_{F,j}^{\dagger}\phi_{E,i}^{\dagger})\}
      + I_{Z} dr \{ \Omega(q'_{EO} sin\theta_{o} - 2q'_{FO} cos\theta_{o} - \beta_{o}) (-\phi'_{F,j} \phi'_{E,i} + \phi'_{E,j} \phi'_{F,i}) \} \Big] \dot{q}_{T,i} \Big\}
     + \left\{ C_{1}(\phi_{\text{FPR,j}} + [L_{2} \tan \alpha_{1}/(R-e)]\phi_{\text{ET,j}}) \sum_{i=1}^{\infty} (\phi_{\text{FPR,i}}) \right\}
      + \left[L_{2} \tan \alpha_{1} / (R-e)\right] \phi_{ET,i} \dot{q}_{T,i} + \left\{2\zeta_{q,j}M_{q,j}\omega_{q,j}\dot{q}_{T,j}\right\}
      + \left\{ \left[ \delta^{R-e} m dr \left\{ \Omega^{2} \left[ \phi_{F,j} \left( a_{2} + e \gamma_{o} \right) - \phi_{E,j} \left( \beta_{o} \left( r + e \right) + b_{2} \right) \right] \right\} \right\}
       + I_{\mathbf{X}} dr\{-\Omega^2 \phi'_{\mathbf{E},\mathbf{j}}(q'_{\mathbf{E}O} \sin 2\theta_o + \beta_o \cos \theta_o)\} + I_{\mathbf{Y}} dr\{\Omega^2 [\phi'_{\mathbf{E},\mathbf{j}}(q'_{\mathbf{E}O} \sin 2\theta_o + \beta_o \cos \theta_o)]\}
       + q'_{FO}^{\cos 2\theta}_{o} + \beta_{o}^{\cos \theta}_{o}) + \phi'_{F,j}(- q'_{EO}^{\cos 2\theta}_{o} + q'_{FO}^{\sin 2\theta}_{o} + \beta_{o}^{\sin \theta}_{o})]
      + I_Z dr \{\Omega^2 [-\phi'_{E,j} q'_{FO} cos 2\theta_o + \phi'_{F,j} (-q'_{FO} sin 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2\theta_o + q'_{EO} cos 2
     =\beta_0 \sin\theta_0) ] \} \Big] \phi_0 \theta_T \Big\{ + \Big\{ -K_1 L_2 \phi_{\theta PR} (\phi_{FPR,j} + [L_2 \tan\alpha_1/(R-e)] \phi_{ET,j}) \theta_T \Big\} \Big\}
      + \left\{ \left[ \left\{ \sum_{i=1}^{R-e} mdr \left\{ \Omega^{2} \left[ -\phi_{E,j} b_{2} \gamma_{0} + \phi_{F,j} \left( a_{2} \gamma_{0} + r + e + 2b_{2} \beta_{0} \right) - v_{1,j} b_{2} \right] \right\} \right\}
        + I_{X}dr\{-\Omega^{2}\phi'_{E,j}\sin\theta_{o}\} + I_{Y}dr\{\Omega^{2}(\phi'_{E,j}\sin\theta_{o}-\phi'_{F,j}\cos\theta_{o})\} \widehat{20}
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 $+ I_{Z} dr \{\Omega^{2} \phi_{F,j}^{\dagger} cos\theta_{0}\} \} \} + \begin{cases} K_{1} L_{2} tan\delta_{3} (\phi_{FPR,j} + [L_{2} tan\alpha_{1}/(R-E)] \phi_{ET,j}) \beta \\ + \begin{cases} \int_{0}^{R-e} m dr \{\Omega^{2}[-\phi_{E,j}(b_{2}\beta_{0}-e)-\phi_{F,j}a_{2}\beta_{0}]\} \} \gamma \\ + \sum_{i=1}^{NE} \int_{0}^{R-e} m dr \{-\Omega^{2}b_{2}\beta_{0}\nu_{2,i,j}\} \\ + \sum_{i=1}^{NE} \int_{0}^{R-e} m dr \{-\Omega^{2}b_{2}\beta_{0}\nu_{2,i,j}\} \\ + I_{X} dr \{\Omega^{2} sin^{2}\theta_{0}\phi_{E,j}^{\dagger}\phi_{E,i}^{\dagger}\} + I_{Y} dr \{\Omega^{2}[\phi_{E,j}^{\dagger}(-\phi_{E,i}^{\dagger} sin^{2}\theta_{0} + \frac{1}{2}\phi_{F,i}^{\dagger} sin^{2}\theta_{0}) \\ + \phi_{F,j}^{\dagger}(\frac{1}{2}\phi_{E,i}^{\dagger} sin^{2}\theta_{0} - \phi_{F,i}^{\dagger} cos^{2}\theta_{0})]\} + I_{Z} dr \{\Omega^{2}[-\frac{1}{2}\phi_{E,j}^{\dagger}\phi_{F,i}^{\dagger} sin^{2}\theta_{0} + \phi_{F,j}^{\dagger}(-\frac{1}{2}\phi_{E,i}^{\dagger} sin^{2}\theta_{0} + \phi_{F,i}^{\dagger} cos^{2}\theta_{0})]\} q_{T,i} \end{cases} + \begin{cases} K_{1}(\phi_{FPR,j} + [L_{2} tan\alpha_{1}/(R-e)]\phi_{ET,j}) \sum_{i=1}^{NE} (\phi_{FPR,i} + [L_{2} tan\alpha_{1}/(R-e)]\phi_{ET,i}) q_{T,i} \end{cases} \\ + \begin{cases} \omega^{2}q, M_{q,j} q_{T,j} \end{cases} = 0$

$$dT = \frac{1}{2} cU[C_L U_T - C_D U_P]$$

$$dH = \frac{1}{2} cU[C_L U_P + C_D U_T]$$

$$dM = \frac{1}{2} cU^2 C_M$$

$$t_1 = \frac{3(dT)}{3U_T} = \frac{1}{2} cC^2 / U_1 C_L (U^2 + U_T^2) - C_D U_T U_P + C_{L,\alpha} U_T U_P$$

$$- C_{D,\alpha} U_P^2] + \frac{1}{2} cC^2 / V_1 C_{L,M} U_T^2 - C_{D,M} U_T U_P]$$

$$t_2 = \frac{3(dT)}{3U_P} = \frac{1}{2} cC^2 / U_1 C_L U_T U_P - C_D (U^2 + U_P^2) - C_{L,\alpha} U_T^2$$

$$+ C_{D,\alpha} U_T U_P] + \frac{1}{2} cC^2 / V_1 C_{L,M} U_T U_P - C_{D,M} U_P^2]$$

$$t_3 = \frac{3(dT)}{3\alpha} = \frac{1}{2} cC^2 / U_1 C_L U_T U_P + C_D (U^2 + U_T^2) + C_{L,\alpha} U_P^2$$

$$+ C_{D,\alpha} U_T U_P] + \frac{1}{2} cC^2 / V_1 C_{L,M} U_T U_P + C_{D,M} U_T^2]$$

$$h_1 = \frac{3(dH)}{3U_P} = \frac{1}{2} cC^2 / U_1 C_L (U^2 + U_P^2) + C_D U_T U_P - C_{L,\alpha} U_T U_P$$

$$- C_{D,\alpha} U_T^2] + \frac{1}{2} cC^2 / V_1 C_{L,M} U_P^2 + C_{D,M} U_T U_P]$$

$$h_3 = \frac{3(dH)}{3\alpha} = \frac{1}{2} cC U_1 C_{L,\alpha} U_P + C_{D,\alpha} U_T$$

$$m_1 = \frac{3(dM)}{3U_T} = \frac{1}{2} cC^2 [C_M 2U_T + C_{M,\alpha} U_P]$$

$$+ \frac{1}{2} cC^2 / V_2 C_{M,M} U_T U$$

$$m_2 = \frac{3(dM)}{3U_P} = \frac{1}{2} cC^2 [C_M 2U_P - C_{M,\alpha} U_T]$$

$$+ \frac{1}{2} cC^2 / V_2 C_{M,M} U_P U$$

 $\mathbf{a}_{\mathbf{a}} = \frac{\partial (d\mathbf{M})}{\partial \alpha} = \frac{1}{2} \alpha \mathbf{c}^2 \mathbf{C}_{\mathbf{M},\alpha} \mathbf{U}^2$

$$\begin{split} \delta U_{T} &= \frac{\partial U_{T}}{\partial q} + \frac{\partial U_{T}}{\partial \dot{q}} \\ &= \sum_{i=1}^{KA} \left\{ \phi_{\theta Y,i} (U_{P} \cos \psi - U_{P} [\gamma_{0} - q'_{EO}] \sin \psi) \right. \\ &- \phi_{\theta X,i} (U_{P} [\gamma_{0} - q'_{EO}] \cos \psi + U_{P} \sin \psi) \}_{\overline{q}_{1}} \\ &- \left\{ \Omega(\alpha \beta_{0} + b q'_{EO}) \right\} \phi_{0} \theta_{T} \\ &- \left\{ \Omega(b + r \beta_{0}) + U_{P} (\gamma_{0} - q'_{EO}) \right\} \beta \\ &- \left\{ \Omega(\gamma_{0} - q'_{EO}) + U_{P} \beta_{0} \right\} \gamma \\ &+ \sum_{i=1}^{K} \left\{ \Omega[\phi'_{E,i} (-a - e \gamma_{0} + (r + e) q'_{EO}) - \phi_{E,i} q'_{EO} - \phi_{F,i} \beta_{0} \right. \\ &+ r_{i}] - U_{P} [\phi'_{E,i} (\beta_{0} + q'_{FO}) + \phi'_{F,i} (\gamma_{0} - q'_{EO})] \}_{q_{T,i}} \\ &+ \sum_{i=1}^{NA} \left\{ \phi_{\theta Y,i} [b(\gamma_{0} - q'_{EO}) \sin \psi - (b + r \beta_{0}) \cos \psi] + \phi_{\theta X,i} [b(\gamma_{0} - q'_{EO}) \cos \psi + (b + r \beta_{0}) \sin \psi] + \phi_{X,i} [(\gamma_{0} - q'_{EO}) \sin \psi - \cos \psi] + \phi_{Y,i} [-(\gamma_{0} - q'_{EO}) \cos \psi + (b + r \phi_{0}) \sin \psi] \right\}_{q_{T,i}} \\ &+ \left\{ b \right\} \phi_{\theta} \delta_{T} \\ &+ \left\{ b \right\} \phi_{\theta} \delta_{T} \\ &+ \left\{ b \left(\gamma_{0} - q'_{EO} \right) \right\} \beta \\ &+ \left\{ r + a q'_{EO} \right\} \gamma \\ &+ \sum_{i=1}^{NA} \left\{ \phi_{\theta Y,i} (-U_{P} (\beta_{0} + q'_{FO}) \sin \psi) - \phi_{\theta X,i} (U_{P} (\beta_{0} + q'_{FO}) \cos \psi) \right\} \overline{q}_{I} \\ &+ \left\{ m b (\beta_{0} + q'_{FO}) \phi_{\theta} \right\} \theta_{T} \\ &+ \left\{ m b (\beta_{0} + q'_{FO}) \phi_{\theta} \right\} \theta_{T} \\ &- \left\{ n (a - r \gamma_{0}) + U_{P} (\beta_{0} + q'_{FO}) \right\} \beta \end{split}$$

$$+ \{\Omega(r\beta_{o} - eq'_{FO})\}\gamma$$

$$+ \sum_{f=1}^{NE} \{\Omega[\phi'_{F,i}(-a + r\gamma_{o}) + \phi_{E,i}(\beta_{o} + q'_{FO})] - U_{P}\phi'_{F,i}(\beta_{o} + q'_{FO})\}q_{T,i}$$

$$+ \sum_{f=1}^{NA} \{(-(a - r\gamma_{o})\cos\psi + (r + e + bq'_{FO} + a\gamma_{o})\sin\psi)\phi_{\theta Y,i}$$

$$+ ((a - r\gamma_{o})\sin\psi + (r + e + bq'_{FO} + a\gamma_{o})\cos\psi)\phi_{\theta X,i}$$

$$+ \phi_{X,i}(\beta_{o} + q'_{FO})\sin\psi - \phi_{Y,i}(\beta_{o} + q'_{FO})\cos\psi$$

$$+ \phi_{Z,i}\}\dot{q}_{i}$$

$$+ \{a\}\phi_{\theta}\dot{\theta}_{T}$$

$$+ \{a\gamma_{o} + r + bq'_{FO}\}\dot{\beta}$$

$$- \{aq'_{FO}\}\dot{\gamma}$$

$$+ \sum_{f=1}^{NE} \{-\dot{r}_{i}q'_{FO} + \phi_{F,i}\}\dot{q}_{T,i}$$

$$\delta\alpha = \frac{\partial\alpha}{\partial q} + \frac{\partial\alpha}{\partial \dot{q}} = \{-1\}\phi_{\theta}\theta_{T}$$

$$\begin{aligned} Q_{\overline{q}_{j}} &= & \left\{ \int_{0}^{R-e} \left[\sum_{n=1}^{N} \left\{ \int_{i=1}^{NA} \left\{ \phi_{\theta X,i} \left[\phi_{\theta Y,j} ((-b_{1}\beta_{0} + a_{1}q'_{EO} + r + e) dH \right. \right. \right. \right. \right. \\ &+ \left. a_{1}(\beta_{0} + q'_{FO}) dT \right] \right] + \phi_{X,j} \left[\phi_{\theta Y,i} dT \right] - \phi_{Y,j} \left[\phi_{\theta X,i} dT \right] \right\} \overline{q}_{i} \\ &+ \left\{ \phi_{\theta X,j} \left[(-a_{1}\sin\psi - a_{1}(\gamma_{0} - q'_{EO})\cos\psi) dH - (b_{1}\sin\psi - (a_{1}q'_{FO} - b_{1}\gamma_{0})\cos\psi) dT \right] \right\} + \phi_{\theta Y,j} \left[(a_{1}\cos\psi - a_{1}(\gamma_{0} - q'_{EO})\sin\psi) dH \right] + \left(b_{1}\cos\psi + (a_{1}q'_{FO} - b_{1}\gamma_{0})\sin\psi) dT \right] \right\} \phi_{\theta} \theta_{T} \\ &+ \left\{ \phi_{\theta X,j} \left[((b_{1}\beta_{0} - r - a_{1}q'_{EO})\sin\psi + e(\gamma_{0} - q'_{EO})\cos\psi) dH \right] \right\} \right. \end{aligned}$$

$$- (a_1(\beta_0 + q'_{FO})\sin\psi + e(\beta_0 + q'_{FO})\cos\psi)dT] + \phi_{HY,j}[((-b_1\beta_0 + r + a_1q'_{EO})\cos\psi + e(\gamma_0 - q'_{EO})\sin\psi)dH + (a_1(\beta_0 + q'_{FO})\cos\psi - e(\beta_0 + q'_{FO})\sin\psi)dT] + \phi_{X,j}\sin\psi dT - \phi_{Y,j}\cos\psi dT + \phi_{Z,j}((\gamma_0 - q'_{EO})dH + q'_{FO})\sin\psi)dT] + \phi_{X,j}\sin\psi dT - \phi_{Y,j}\cos\psi dT + \phi_{Z,j}((\gamma_0 - q'_{EO})dH + q'_{FO})dT)] + (\phi_0 + q'_{FO})\sin\psi + (e\beta_0 - b_1)\cos\psi)dH - ((b_1q'_{FO} + a_1\gamma_0 + r + r + q'_{FO})\sin\psi)dT] + ((b_1q'_{FO} - a_1\gamma_0 - r + r + q'_{FO})\cos\psi - (e\beta_0 + q'_{FO})\sin\psi)dT] + ((b_1q'_{FO} - a_1\gamma_0 - r + q'_{FO})\sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO})\cos\psi + sin\psi)dH - q'_{FO}\cos\psi dT] - \phi_{Y,j}[((\gamma_0 - q'_{EO})\sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO})\cos\psi + sin\psi)dH - q'_{FO}\cos\psi dT] - \phi_{Y,j}[((\gamma_0 - q'_{EO})\sin\psi)dT] + (\phi_{X,j}[((\gamma_0 - q'_{EO})\cos\psi + sin\psi)dT] + \phi_{X,j}[(\gamma_0 - q'_{EO})\sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO})\cos\psi + sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO}))\cos\psi + sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO}))\phi'_{X,j} + sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO}))\phi'_{X,j} + sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO}))\phi'_{X,j} + sin\psi)dT] + \phi_{X,j}[((\gamma_0 - q'_{EO}))\phi'_{X,j}]\cos\psi + (\phi_{X,j}[(\gamma_0 - q'_{EO}))\phi'_{X,j}]\sin\psi + (\phi_{X,j}[(\gamma_0 - q'_{EO}))\phi'_{X,j}]\sin\psi + \phi'_{X,j}[((\gamma_0 - q'_{EO}))\phi'_{X,j}]((\gamma_0 - q'_{EO}))\phi'_{X,j}]\sin\psi + \phi'_{X,j}[(\gamma_0 - q'_{EO}))\phi'_{X,j}]((\gamma_0 - q'_{EO}))\phi'_{X,j}]\sin\psi + \phi'_{X,j}[(\gamma_0 - q'_{EO}))\phi'_{X,j}]((\gamma_0 - q'_{EO}))\phi$$

$$\begin{array}{l} + b_{1}q^{\prime}_{FO}) - \phi_{\theta Y,j}(a_{1} - r \gamma_{o}) \\ - \phi_{Y,j}(\beta_{o} + q^{\prime}_{FO}))\cos\psi + (\phi_{\theta X,j}(a_{1} - r \gamma_{o}) + \phi_{\theta Y,j}(a_{1} \gamma_{o} + r + e \\ + b_{1}q^{\prime}_{FO}) + \phi_{X,j}(\beta_{o} + q^{\prime}_{FO}))\sin\psi + \phi_{Z,j}][t_{1}\delta U_{T} + t_{2}\delta U_{P} + t_{3}\delta \alpha] \\ + [(-\phi_{\theta X,j})_{1}(\gamma_{o} - q^{\prime}_{EO}) + \phi_{\theta Y,j}(b_{1} + r \beta_{o}) + \phi_{Y,j}(\gamma_{o} - q^{\prime}_{EO}) \\ + \phi_{X,j})\cos\psi - (\phi_{\theta X,j}(b_{1} + r \beta_{o}) + \phi_{\theta Y,j}b_{1}(\gamma_{o} - q^{\prime}_{EO}) + \phi_{X,j}(\gamma_{o} - q^{\prime}_{EO}) \\ - \phi_{Y,j})\sin\psi][h_{1}\delta U_{T} + h_{2}\delta U_{P} + h_{3}\delta \alpha]]]dr \\ \\ Q_{\theta T} = \begin{cases} \delta^{R-e} \Big[(-a_{1}dH - b_{1}dT)\phi_{\theta}^{2}\theta_{T} \\ + \sum_{i=1}^{2} ((-\phi_{F,i} - \phi^{\prime}_{E,i}q^{\prime}_{EO}b_{1})dH - (\phi_{E,i} + \phi^{\prime}_{E,i}q^{\prime}_{FO}b_{1} \\ - \phi^{\prime}_{F,i}(q^{\prime}_{EO}b_{1} - q^{\prime}_{FO}a_{1}))dT)\phi_{\theta}q_{T,i} \\ + a_{1}(t_{1}\delta U_{T} + t_{2}\delta U_{P} + t_{3}\delta \alpha)\phi_{\theta} \\ - b_{1}(h_{1}\delta U_{T} + t_{2}\delta U_{P} + t_{3}\delta \alpha)\phi_{\theta} \\ - (m_{1}\delta U_{T} + m_{2}\delta U_{P} + m_{3}\delta \alpha)\phi_{\theta} \Big]dr \\ \\ Q_{\theta} = \begin{cases} \delta^{R-e} \Big[(-a_{1}(\gamma_{o} - q^{\prime}_{EO})dH - (b_{1}\gamma_{o} - a_{1}q^{\prime}_{FO})dT)\phi_{\theta}\theta_{T} \\ - (b_{1}dH - (a_{1} - r\gamma_{o})dT)\gamma \\ + \sum_{i=1}^{RE} ((-\phi_{F,i}(\gamma_{o} - q^{\prime}_{EO}) - \phi^{\prime}_{E,i}b_{1})dH - (\phi_{E,i}\gamma_{o} - \phi_{F,i}q^{\prime}_{FO}) \\ - r_{i} - \phi^{\prime}_{F,i}(b_{1} - rq^{\prime}_{FO})(t_{1}\delta U_{T} + t_{2}\delta U_{P} + t_{3}\delta \alpha) \\ - (b_{1}(\gamma_{o} - q^{\prime}_{EO}))(h_{1}\delta U_{T} + h_{2}\delta U_{P} + h_{3}\delta \alpha) \Big]dr \\ \end{cases}$$

$$Q_{\gamma} = \begin{cases} \begin{cases} R^{-e} \left[(b_{1}q'_{E0}dH + b_{1}q'_{F0}dT)\phi_{\theta}\theta_{T} \\ + \sum_{i=1}^{NE} ((\phi_{E,i}q'_{E0} - r_{i} + \phi'_{E,i}(a_{1} - rq'_{E0}))dH \\ + (\phi_{E,i}q'_{F0} - r\phi'_{E,i}q'_{F0} - \phi'_{F,i}(a_{1} - rq'_{E0}))dT)q_{T,i} \\ - (a_{1}q'_{F0})(t_{1}\delta U_{T} + t_{2}\delta U_{P} + t_{3}\delta \alpha) \\ - (a_{1}q'_{E0} + r)(h_{1}\delta U_{T} + h_{2}\delta U_{P} + h_{3}\delta \alpha) \right] dr \end{cases}$$

$$Q_{q_{T,j}} = \begin{cases} \begin{cases} R^{-e} \left[(-\phi_{F,j}dH - \phi_{E,j}dT)\phi_{\theta}\theta_{T} \\ + \sum_{i=1}^{NE} ((-q'_{E0}r_{j,i} - \phi'_{E,i}(q'_{E0}\phi_{E,j} - r_{j}))dH \\ - (q'_{F0}\phi_{E,j}\phi'_{E,i} + \phi'_{F,i}(-q'_{E0}\phi_{E,j} + r_{j} + q'_{F0}\phi_{F,j}) \\ + q'_{F0}r_{j,i}dT)q_{T,i} \\ + \phi_{F,j}(t_{1}\delta U_{T} + t_{2}\delta U_{P} + t_{3}\delta \alpha) \\ - \phi_{E,j}(h_{1}\delta U_{T} + h_{2}\delta U_{P} + h_{3}\delta \alpha) \right] dr \end{cases}$$

$$(46)$$

LIST OF SYMBOLS

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$$a = q_{FO} + (^{C}/_{4} - EA)\cos\theta_{O}$$

$$a_1 = q_{E0} - ACcos\theta_0$$

$$a_2 = q_{E0} - CG\cos\theta_0$$

$$a_h = EA/b_h$$

AC Distance from blade elastic axis to aerodynamic center-positive toward leading edge.

L₂ Distance from blade elastic axis to pushrod: positive toward leading edge.

 L_{2} Radial location of blade pitch horn.

 L_1 Length of one arm of tail rotor blade pitch spider beam.

L_s Length of tail rotor pitch beam arm.

m Blade elemental mass

 ${\rm M}_{\rm G}$ Airframe mode generalized mass.

 M_{Ω} Generalized mass of blade bending modes.

 ${\rm M}_{\rm A}$ Generalized mass of fixed system modes.

M₁ Mass at pushrod.

M Mach number.

Partial derivative of pitching moment with respect to local blade tangential velocity.

Partial derivative of pitching moment with respect to local blade vertical velocity.

Partial derivative of pitching moment with respect to local blade angle of attack.

n Blade number.

N Number of blades.

NE Number of blade bending modes.

2 - 1 - 1

NA Number of fixed system modes.

h₃ Partial derivative of drag with respect to local blade angle of attack.

I Blade flatwise, edgewise, torsional mass moment of inertia matrix.

 ${\bf I}_{{\bf A}}$ Blade torsional mass moment of inertia.

 $I_{\gamma\gamma}$ Blade edgewise second moment of area.

 I_{χ} Elemental blade flatwise mass moment of inertia.

 I_{γ} Elemental blade torsional mass moment of inertia.

I₇ Elemental blade chordwise mass moment of inertia.

 I_{T} Total blade torsional mass moment of inertia.

 I_{γ} Blade mass moment of inertia about lag hinge.

J Local blade polar second moment of area.

K Blade torsional stiffness.

 K_{G} Airframe mode generalized stiffness.

 K_{γ} Blade lag hinge spring rate.

 K_{g} Blade flapping hinge spring rate.

K₁ Pitch beam stiffness or stiffness at main or tail rotor blade pushrod.

 $K_{\mbox{MA}}$ Stiffness of tail rotor pitch actuator for pure moment applied at pitch beam end.

C_{M,M} Partial derivative of pitching moment coefficient with respect to Mach number.

CG Distance from blade elastic axis to center of gravity--positive toward leading edge.

dL Elemental lift.

dD Elemental drag.

dM Elemental pitching moment.

dT Elemental thrust. dH Elemental inplane force. e Blade offset. FA Distance from blade semi-chord to elastic axis-positive toward trailing edge. G Blade torsional modulus of elasticity. Partial derivative of drag with respect to local blade tangential h_1 velocity. Partial derivative of drag with respect to local blade vertical h₂ velocity. Fixed system mode generalized coordinate. q_i $Q_{T,j}$ Blade bending mode generalized coordinate--bending up and leading positive. Steady blade flatwise deflection--up positive. q_{F0} Steady blade inplane deflection--lag positive. Q_{FO} Hub pitch coordinate. $q_{\Theta X}$ Hub roll coordinate. \overline{q}_{AY} \overline{q}_{χ} Hub lateral coordinate. Hub longitudinal coordinate. q_{γ} Hub vertical coordinate. q Collective mode coordinate. q_0 Reactionless mode coordinate. q_n Sine cyclic coordinate. q_s Cosine cyclic coordinate. qc

q_{F01} q_{F0s} Blade flatwise bending slope steady, and sine and cosine coefficient components. Generalized forces. q_{F0c} Generalized force on j'th fixed system mode. Generalized force on blade pitch. $Q_{\Theta T}$ Generalized force on blade flapping. Q_{B} Generalized force on blade lagging. Q_{γ} $Q_{q_T,j}$ Generalized force on j'th blade bending mode. $Q_{\mathbf{j}}$ Generalized aerodynamic force. Radius of local blade element from offset. r Radial location of inner snubber of crossbeam rotor. r_1 Radial location of outer snubber of crossbeam rotor. r_2 R Rotor radius. Radius to servo connections on main rotor swash plate. R_{ς} Radius to pushrod connections on main rotor swash plate. R_{R} Partial derivative of thrust with respect to local blade t_1 tangential velocity. Partial derivative of thrust with respect to local blade t_2 vertical velocity. Partial derivative of thrust with respect to local blade angle t_3 of attack. U Total local blade inflow velocity. $U_{\mathbf{p}}$ Local blade vertical velocity.

Local blade tangential velocity.

 U_{T}

v Speed of sound.

V Potential energy.

 V_A Rotor axial velocity.

V_F Forward-flight speed.

 X_1 Displacement at blade pushrod.

α Local blade angle of attack.

 α_1 Pitch-lag coupling--lead, pitch-up positive.

β Blade rigid-body flapping generalized coordinate--up positive.

 β_0 Steady blade coning--up positive.

γ Blade rigid-body lag generalized coordinate--lead positive.

 γ_0 Steady blade lag--lead positive.

 δ_3 Pitch-flap coupling--flap up, pitch down positive.

Fraction of critical structural damping of blade bending modes—based on modal frequency.

 $\boldsymbol{\zeta}_{\boldsymbol{\theta}}$ Fraction of critical structural damping of blade pitch mode-based on rotor speed.

Fraction of critical rigid-body lag damping--based on uncoupled lag frequency.

Fraction of critical structural damping of fixed system modes—based on modal frequency.

θ Blade pitch generalized coordinate--leading edge down positive.

 θ_{Ω} Steady blade pitch angle--leading edge down positive.

 θ_T Blade pitch normal coordinate.

 θ_{p} Geometric blade pitch angle--leading edge up positive.

 $v_1 = (f'(-\phi'_{E,i}q'_{E0} + \phi'_{F,i}q'_{F0})dr) = -r_i$

 $v_2 = (\int_0^r (\phi'_{E,i} \phi'_{E,j} + \phi'_{F,i} \phi'_{F,j}) dr) = \dot{r}_i = r_{i,j}$

 ρ Air mass density.

Local blade inflow angle.

 $^{\phi}$ X,Y,Z Fixed system translational mode shapes at hub.

 $^{\phi}\theta X, \theta Y$ Fixed system rotational mode shapes at hub.

 ϕ_F Blade flatwise bending mode shape.

 ϕ_F Blade inplane bending mode shape.

 ϕ_{A} Blade torsional mode shape.

 $\phi_{\theta PR}$ Blade torsional mode shape at pushrod radial station.

φFPR Blade flatwise bending mode shape at pushrod radial station.

 ϕ_{ET} Blade inplane bending mode shape at tip radius.

 ψ Blade azimuthal angle.

 ω_{T1} Blade asymmetric torsional frequency.

 ω_{T2} Blade symmetric torsional frequency.

 ω_p Hub pitch frequency.

 ω_{γ} Hub yaw frequency.

 ω_{FN} Blade edgewise natural frequency.

 ω_{q} Frequency of blade bending modes.

 ω_{\sim} Uncoupled rigid-body lag frequency.

 ω_{A} Frequency of fixed system modes.

ω Flutter frequency.

 Ω Rotor speed.

Subscripts

i Refers to blade element or mode number.

j Refers to mode or force number.

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S
          Refers to mode number.
t
          Refers to blade number.
n
          Refers to pushrod.
PR
X
          Refers to hub lateral, longitudinal, and vertical directions.
Υ
Ż
          Refers to hub pitch and roll directions.
θх
θY
Superscripts
          Menas coupled.
          Means uncoupled.
u
Differential Notation
          Differentiation with respect to radius.
          Differentiation with respect to time.
```

Second differential with respect to time.

D.4 Fuselage Dynamic Representation

The fuselage math model is presented by equation (47), shown in Figure D.4-1. It consists of up to sixteen rigid and/or elastic mode shapes. For this modal representation we need the generalized masses (Mgi), frequencies (ω_{ni}) and damping (ε_{i}) for these mode shapes. We also need the modal components at any point on the aircraft where forces and moments are applied.

Obtaining the generalized coordinates, q_i , one can then evaluate the response at any point on the aircraft using equation (48), see Figure D.4-1.

$$m_{gi} q_{i} + 25_{i} m_{gi} w_{i} q_{i} + m_{gi} w_{i}^{2} q_{i} = \phi_{Hi}^{T} \cdot F_{i} + \sum_{k=1}^{N} \phi_{ki}^{T} F_{ki}$$

$$(47)$$

N = TOTAL NUMBER OF AIRCRAFT POINTS WHERE EXCITATIONS APPLIED

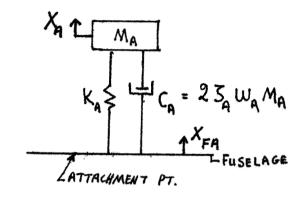
$$X_{k} = \Phi_{ki} \cdot q_{i} \tag{48}$$

Xk = RESPONSE VECTOR AT KIN POINT ON AIRCRAFT.

FIGURE D.4-1: FUSELAGE MATH MODEL

D.5 Fixed System Absorber

The math model of the fixed system absorber is shown in Figure D.5-1. It is a one degree of freedom spring-mass system. The kinetic and potential energies of the system are given by equations (49) and (50) respectively, shown in Figure D.5-1. Substituting into Lagrange's equation results in the equation of motion for the fixed absorber shown in Figure D.5-1 by equation (51).



K.E. =
$$\frac{1}{2} M_A (\dot{X}_A + \dot{X}_{FA})^2$$
 (49)

P.E. =
$$\frac{1}{2} K_A X_A^2$$
 (50)

$$\omega_A^2 = \frac{K_A}{M_A}$$

THUS:

$$[M]{\ddot{x}} + [C]{\dot{x}} + [K]{X} = 0$$
 (51)

D.5-1: FIXED SYSTEM ABSORBER

$$\left\{X\right\} = \left\{\frac{X_{FA}}{X_{A}}\right\}$$

$$[M] = \begin{bmatrix} M_A & M_A \\ M_A & M_A \end{bmatrix}; \quad [C] = \begin{bmatrix} O & O \\ O & 25_A \omega_A M_A \end{bmatrix}$$

$$[K] = \begin{bmatrix} O & O \\ O & M_A w_A^2 \end{bmatrix}$$

D.6 Assembly of Coupled Equations

To assemble the coupled equations of motion we need to know the modal components, of the same mode shapes used in Section D.4, at any aircraft point where the rotor, fixed and rotating absorbers are attached.

Here we will demonstrate the procedure used to couple the fixed system with that of the rotor. This same technique is used to couple the bifilars and fixed absorbers with the fixed system.

Equation (52) in Figure D.6-1 shows the rotor equation of motion in general form. We partitioned the mass, stiffness and damping matrices into submatrices associated with the hub (attachment point) and rotor degrees of freedom, see equation (53) Figure D.6-1.

The hub degrees of freedom are related to the fuselage (generalized) degrees of freedom by equation (54) shown in Figure D.6-1. Thus equation (53) can be transformed into equation (55) whose state vector consists of the fuselage and rotor degrees of freedom, as shown in Figure D.6-2.

With the hub degrees of freedom replaced by the generalized degrees of freedom, q's, we can now combine the rotor and fuselage equations of motion, as shown by equation (56) in Figure D.6-2.

$$[M] \cdot {\ddot{X}} + [C] {\dot{X}} + [K] \cdot {X} = {F}$$
 (52)

$$\begin{bmatrix}
M_{HH} & M_{HR} \\
M_{RH} & M_{RR}
\end{bmatrix}
\begin{bmatrix}
\ddot{X}_{R} \\
\ddot{X}_{R}
\end{bmatrix}
+
\begin{bmatrix}
C_{HH} & C_{HR} \\
C_{RH} & C_{RR}
\end{bmatrix}
\begin{bmatrix}
\dot{X}_{H} \\
\dot{X}_{R}
\end{bmatrix}
+
\begin{bmatrix}
K_{HH} & K_{HR} \\
K_{RH} & K_{RR}
\end{bmatrix}
\begin{bmatrix}
X_{H} \\
X_{R}
\end{bmatrix}
\begin{bmatrix}
F_{R} \\
K_{RH} & K_{RR}
\end{bmatrix}
\begin{bmatrix}
X_{H} \\
X_{R}
\end{bmatrix}
\begin{bmatrix}
F_{R} \\
K_{RH}
\end{bmatrix}$$
(53)

$${X_{H}}$$
 = HUB DEGREES OF FREEDOM, (6×1)
 ${X_{R}}$ = ROTOR DEGREES OF FREEDOM, $(n_{R} \times 1)$

$$\{X_{\mu}\} = [\phi_{\mu}] \cdot \{q\} \tag{54}$$

WHERE :

$$\{q\}$$
 = Fuselage Degrees of Freedom $(M_F \times L)$
 $[\phi_H]$ = Hub Mode Shapes $(6 \times M_F)$

Figure D.6-1: Uncoupled Equations of Motion

$$\begin{bmatrix} [\Phi_{H}]^{T} [M_{HH}] \cdot [\Phi_{H}] \\ [M_{RH}] \cdot [\Phi_{H}] \\ [M_{RR}] \end{bmatrix} \begin{bmatrix} [\Phi_{H}]^{T} [M_{HR}] \\ [M_{RR}] \end{bmatrix} \begin{cases} [\Phi_{H}]^{T} [C_{HR}] \\ [C_{RH}] \cdot [\Phi_{H}] \\ [C_{RR}] \end{bmatrix} \begin{bmatrix} [\Phi_{H}]^{T} [C_{HR}] \\ [C_{RR}] \end{bmatrix} \begin{cases} [\Phi_{H}]^{T} [K_{HR}] \\ [K_{RR}] \end{bmatrix} \begin{cases} [\Phi_{H}]^{T} [K_{HR}] \\ [K_{RR}] \end{bmatrix} \begin{cases} [\Phi_{H}]^{T} [K_{HR}] \\ [K_{RR}] \end{cases} (55)$$

$$\begin{bmatrix} M_{\text{gw}} \end{bmatrix} + \begin{bmatrix} \phi_{\text{H}} \end{bmatrix}^{\text{T}} \begin{bmatrix} M_{\text{HH}} \end{bmatrix} \cdot \begin{bmatrix} \phi_{\text{H}} \end{bmatrix}^{\text{T}} \cdot \begin{bmatrix} M_{\text{HR}} \end{bmatrix}^{\text{T}} \cdot \begin{bmatrix}$$

$$\begin{bmatrix}
25m_{g}\omega \\
 \end{bmatrix} + [\phi_{H}]^{T} [C_{HH}] \cdot [\phi_{H}] \\
 [C_{RH}] \cdot [\phi_{H}] \\
 [C_{RR}]
\end{bmatrix} \cdot (\phi_{H}) + (\phi_{H})^{T} [C_{HR}] \cdot (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T} (\phi_{H}) + (\phi_{H})^{T$$

Figure D.6-2: Procedure to Form Coupled Equations (Concluded)

D.7 Forced Response Solution

The final math model is represented by equation (57) of Figure D.7-1, where the state vector, X, consists of the fuselage, rotor, fixed and rotating absorbers degrees of freedom.

A solution of the form shown by equation (58) is assumed which after substitution in equation (57) results in equation (59), see Figure D.7-1. Expressing the state vector, $X_{\rm C}$ and $X_{\rm S}$ in terms of the sine and cosine components of the fuselage and remaining degrees of freedom, see equation (60) Figure D.7-1, and substituting it into equation (59) gives equation (61) from which equation (62) immediately follows after grouping like degrees of freedom. The form of equation (62) is preferred over that of equation (61) since the size of the inverse matrices involved in the solution is greatly reduced. From equations (62) the solutions for q and γ are expressed by equations (63) and (64) respectively, see Figure D.7-1.

$$[M]{\ddot{x}} + [c]{\dot{x}} + [K]{X} = {F}$$
 (57)

$$\{X\} = \{X_s\} \sin \omega_s t + \{X_c\} \cos \omega_f t \qquad (58)$$

$$[[K] - \omega_{f}^{2}[M]]\{X_{c}\} + \omega_{f}[c]\{X_{s}\} = \{F_{c}\}\$$

$$-\omega_{f}[c]\{X_{c}\} + [[K] - \omega_{f}^{2}[M]]\{X_{s}\} = \{F_{s}\}\$$
(59)

$$\left\{\chi_{c}\right\} = \left\{\frac{q_{c}}{\gamma_{c}}\right\} \qquad \text{and} \quad \left\{\chi_{s}\right\} = \left\{\frac{q_{s}}{\gamma_{s}}\right\} \qquad (60)$$

[q] AND [q] ARE THE COSINE AND SINE COMPONENTS OF THE FUSELAGE DEGREES OF FREEDOM

{YC} AND {YS} ARE THE COSINE AND SINE COMPONENTS OF THE ROTOR, FIXED ABSORBERS AND ROTATING ABSORBERS DEGREES OF FREEDOM

Figure D.7-1: Forced Response Solution (Continued)

$$\begin{bmatrix}
-\omega_{t}[c] & \omega_{t}[M] & \omega_{t}[c] \\
-\omega_{t}[c] & \omega_{t}[M]
\end{bmatrix}
\begin{bmatrix}
q_{c} \\
\chi_{c} \\
q_{s} \\
\chi_{s}
\end{bmatrix} = \begin{cases}
F_{c} \\
O \\
F_{s} \\
O
\end{cases}$$
(61)

$$\begin{bmatrix}
[E] & [F] \\
[G] & [H]
\end{bmatrix}
\begin{cases}
q_c \\
q_s \\
y_s
\end{cases}
=
\begin{cases}
F_c \\
F_s \\
0 \\
0
\end{cases}$$
(62)

$$\left[\left[F \right] - \left[F \right] \left[H \right]^{-1} \left[G \right] \right] \left\{ \begin{array}{c} q_c \\ q_s \end{array} \right\} = \left\{ \begin{array}{c} F_c \\ F_s \end{array} \right\}$$
 (63)

$$\begin{cases} y_s \\ y_s \end{cases} = [H]'[G] \begin{Bmatrix} q_s \\ q_s \end{Bmatrix}$$
 (64)

Figure D. 7-1: Forced Response Solution (Concluded)

D.8 Time History Solution

We have shown previously the technique used to couple the equations of motion of the fixed system, rotor, fixed absorber, and the linear bifilar transferred to fixed system coordinates. The final equation we arrived at is of the form shown by equation (65), Figure D.8-1. We can rewrite equation (65) in the form shown by equation (66), Figure D.8-2, where the right-hand-side of the equation is replaced by a forcing vector. The non-linear inplane bifilar equations of motion, shown in Figure D.1-3, can be rewritten in the compact form shown in equation (67), Figure D.8-2. Using the coupling technique described in section D.6 we can also couple equations (66) and (67). The resultant coupled mass matrix and force vector are shown in Figure D.8-2 by equations (68) and (69) respectively. The state vector is expanded and consists of the fuselage, rotor, fixed absorber, linear inplane and/or vertical bifilar in the fixed system coordinate, and non-linear inplane bifilar degrees of freedom. The final equations of motion of the system can be rewritten as shown by equation (70) Figure D.8-2. The reason for partitioning the matrix as shown in equation (70) is that the submatrix D has been reduced to the identity matrix and the only inversion required for solution is that of a matrix whose dimension is much smaller than that of the total mass matrix as shown in equation (9). This saves considerable computer time and in addition it is more stable.

Solving equations (71) and (72), shown in Figure D.8-3, we get the acceleration vector. The velocity and displacement vector are updated by equations (73). This procedure is repeated until the state variable, X, have converged within the specified constraints.

$$\begin{bmatrix}
M_{q} \\
M_{q} \\
M_{Rq}
\end{bmatrix} = \begin{bmatrix}
M_{q_R} \\
M_R
\end{bmatrix} + \begin{bmatrix}
M_{q_{RR}} \\
O \\
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FIGURE D.8-1: COUPLED EQUATIONS OF MOTION

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$$\left[\begin{bmatrix} M_{H}(\psi) \end{bmatrix} & \begin{bmatrix} M_{HB}(\psi) \end{bmatrix} \\ M_{BH}(\psi) \end{bmatrix} & \begin{bmatrix} \ddot{X}_{H} \\ \ddot{Y} \end{bmatrix} = \begin{cases} F_{H}(\psi) \\ F_{V}(\psi) \end{cases}$$
(67)

$$\begin{bmatrix} M_{q} \end{bmatrix} + \begin{bmatrix} \Phi_{H} \end{bmatrix}^{T} \begin{bmatrix} M_{H} \end{bmatrix} \cdot \begin{bmatrix} \Phi_{H} \end{bmatrix} & \begin{bmatrix} M_{qR} \end{bmatrix} & \begin{bmatrix} M_{qFA} \end{bmatrix} & M_{qLB} & \begin{bmatrix} \Phi_{H} \end{bmatrix}^{T} \cdot \begin{bmatrix} M_{HB} \end{bmatrix} \\ & \begin{bmatrix} M_{RQ} \end{bmatrix} & \begin{bmatrix} M_{R} \end{bmatrix} & O & O & \begin{bmatrix} M_{FA} \end{bmatrix} & O & O & \begin{bmatrix} M_{BR} \end{bmatrix} & O & O & \begin{bmatrix} M_{BR} \end{bmatrix} & O$$

FIGURE D.8-2: COUPLED EQUATIONS OF MOTION (CONTINUED)

(68)

$$\begin{bmatrix}
\begin{bmatrix} A \end{bmatrix} & \begin{bmatrix} B \end{bmatrix} \\
\hline \begin{bmatrix} C \end{bmatrix} & \begin{bmatrix} D \end{bmatrix}
\end{bmatrix}
\begin{cases}
\ddot{X}_1 \\
\ddot{X}_2
\end{cases} = \begin{cases}
F_1 \\
F_2
\end{cases}$$
(70)

$$\left\{X_{1}\right\} = \left\{\begin{array}{c} q \\ \overline{X_{R}} \end{array}\right\} \qquad \text{AND} \qquad \left\{X_{2}\right\} = \left\{\begin{array}{c} X_{FR} \\ \overline{X_{LB}} \\ \overline{X} \end{array}\right\}$$

X_R = ROTOR DEGREES OF FREEDOM

X_{FA} = FIXED ABSORBER DEGREES OF FREEDOM

X_{LB} AND Y = LINEAR (TRANF. TO FIX SYSTEM) AND N.L. BIFILAR

DEGREES OF FREEDOM.

FIGURE D.8-2: COUPLED EQUATIONS OF MOTION (CONCLUDED)

$$\{\ddot{x}_i\} = [A] - [B][C]^{-1} \cdot \{\{F_i\} - [B] \cdot \{F_2\}\} (71)$$

$$\left\{\ddot{X}_{2}\right\} = \left\{F_{2}\right\} - \left[c\right] \cdot \left\{\ddot{X}_{1}\right\} \tag{72}$$

SINCE :

$$\begin{cases} \dot{X}_{1} _{NEW} \end{cases} = \begin{cases} \dot{X}_{1} _{OLD} \end{cases} + (\Delta T) \begin{cases} \ddot{X}_{1} _{NEW} \end{cases}$$

$$\begin{cases} X_{1} _{NEW} \end{cases} = \begin{cases} X_{1} _{OLD} \end{cases} + (\Delta T) \begin{cases} \dot{X}_{1} _{NEW} \end{cases}$$

$$\begin{cases} \dot{X}_{2} _{NEW} \end{cases} = \begin{cases} \dot{X}_{2} _{OLD} \end{cases} + (\Delta T) \begin{cases} \ddot{X}_{2} _{NEW} \end{cases}$$

$$\begin{cases} X_{2} _{NEW} \end{cases} = \begin{cases} X_{2} _{OLD} \end{cases} + (\Delta T) \begin{cases} \dot{X}_{2} _{NEW} \end{cases}$$

FIGURE D.8-3: SOLUTION OF COUPLED EQUATIONS OF MOTION

D.9 List	of Symbols
^{M}A	Fixed absorber mass
M _{Gi} , m _{gi}	Generalized masses
M_{T}	Total bifilar mass
m	Individual bifilar mass
N	Total number of bifilars
n	Bifilar tuning
q _i	Generalized coordinates
R	Distance from center of bifilar tracking hole to center of rotation \ensuremath{I}
r	Equivalent pendulum arm
x_A	Vertical motion of fixed system absorber
x _{FA}	Vertical motion of attachment point of fixed absorber and fuselage
Х	Rotating coordinate system
ХI	Inertia coordinate system
w _A	Fixed absorber tuning frequency
w _i	Generalized frequencies
Ψ _β	Vertical bifilar tuning frequency
$\mathbf{w}_{\mathbf{y}}$	Inplane bifilar tuning frequency
β	Vertical bifilar degree of freedom
Υ	Inplane bifilar degree of freedom
ζA	Fixed absorber damping
ζβ	Vertical bifilar damping
ζ _γ	Inplane bifilar damping

```
Generalized damping
ζį
           Mode shapes
            Bifilar arm angle of rotation
            Rotor speed
Ω
            Hub roll
            Hub pitch
θz
            Hub yaw
            Hub longitudinal modal damping
            Hub lateral modal damping
\zeta_{y}
            Hub vertical modal damping
ζ,
            Hub roll modal damping
\zeta_{\theta x}
            Hub pitch modal damping
\zeta_{\theta y}
            Hub yaw modal damping
\zeta_{\theta Z}
            Hub longitudinal modal frequency
W<sub>X</sub>
            Hub lateral modal frequency
Wy
            Hub vertical modal frequency
w_{\theta x}
            Hub roll modal frequency
            Hub pitch modal frequency
w_{\theta y}
            Hub yaw modal frequency
W_{\theta z}
Subscripts
H, h
            Hub
HR
            Hub-Rotor
            Fixed system mode
i
            k<sup>th</sup> bifilar
k
R
            Rotor
```

Differential Notation

- . Differentiation with respect to time
- .. Second differential with respect to time

Matrix Definitions

C Damping matrix

C_{HH} Hub damping sub-matrix

 $C_{\mbox{\scriptsize HR}}$ Hub/rotor damping coupled sub-matrix

C_{RH} Rotor/hub damping coupled sub-matrix

 ${\bf C}_{\sf RR}$ Rotor damping sub-matrix

 ${\tt C_q}$ Generalized fuselage damping sub-matrix

 C_{qR} Generalized fuselage/rotor damping coupled sub-matrix

 $C_{\mbox{\scriptsize Rq}}$ Rotor/generalized fuselage damping coupled sub-matrix

 C_{qFA} Generalized fuselage/fixed absorber damping coupled sub-matrix

 ${\sf C}_{\sf FAa}$ Fixed absorber/generalized fuselage damping coupled sub-matrix

 ${f C}_{{f qLB}}$ Generalized fuselage/linear bifilar damping coupled sub-matrix

 ${\bf C}_{\sf LBq}$ Linear bifilar/generalized fuselage damping coupled sub-matrix

F Force vector

 F_{AP} Force vector at any point on the aircraft

 F_{C} Cosine component of generalized force vector

 F_{ς} Sine component of generalized force vector

 ${\bf F}_{\bf H}$ Force vector at hub

 ${\sf F}_{\sf R}$ Force vector at hub due to rotor

K Stiffness matrix

K_{HH} Hub stiffness sub-matrix

 $K_{\mbox{HR}}$ Hub/rotor stiffness coupled sub-matrix

K _{RH}	Rotor/hub stiffness coupled sub-matrix
K _{RR}	Rotor stiffness sub-matrix
Kq	Generalized fuselage stiffness sub-matrix
K_{qR}	Generalized fuselage/rotor stiffness coupled sub-matrix
K _{Rq}	Rotor/generalized fuselage stiffness coupled sub-matrix
KqFA	Generalized fuselage/fixed absorber stiffness coupled sub-matrix
K _{FAq}	Fixed absorber/generalized fuselage stiffness coupled sub-matrix
K_{qLB}	Generalized fuselage/linear bifilar stiffness coupled sub-matrix
K _{LBq}	Linear bifilar/generalized fuselage stiffness coupled sub-matrix
М	Mass matrix
M_{HH}	Hub mass matrix
M _{HR}	Hub/rotor mass coupled sub-matrix
M _{RH}	Rotor/hub mass coupled sub-matrix
M _{RR}	Rotor mass sub-matrix
M _q	Generalized fuselage mass sub-matrix
M_{qR}	Generalized fuselage/rotor mass coupled sub-matrix
M_{Rq}	Rotor/generalized fuselage mass coupled sub-matrix
M _{qFA}	Generalized fuselage/fixed@absorber mass coupled sub-matrix
M _{FAq}	Fixed absorber/generalized fuselage mass coupled sub-matrix
M _{qLB}	Generalized fuselage/linear bifilar mass coupled sub-matrix
M _{LBq}	Linear bifilar/generalized fuselage mass coupled sub-matrix